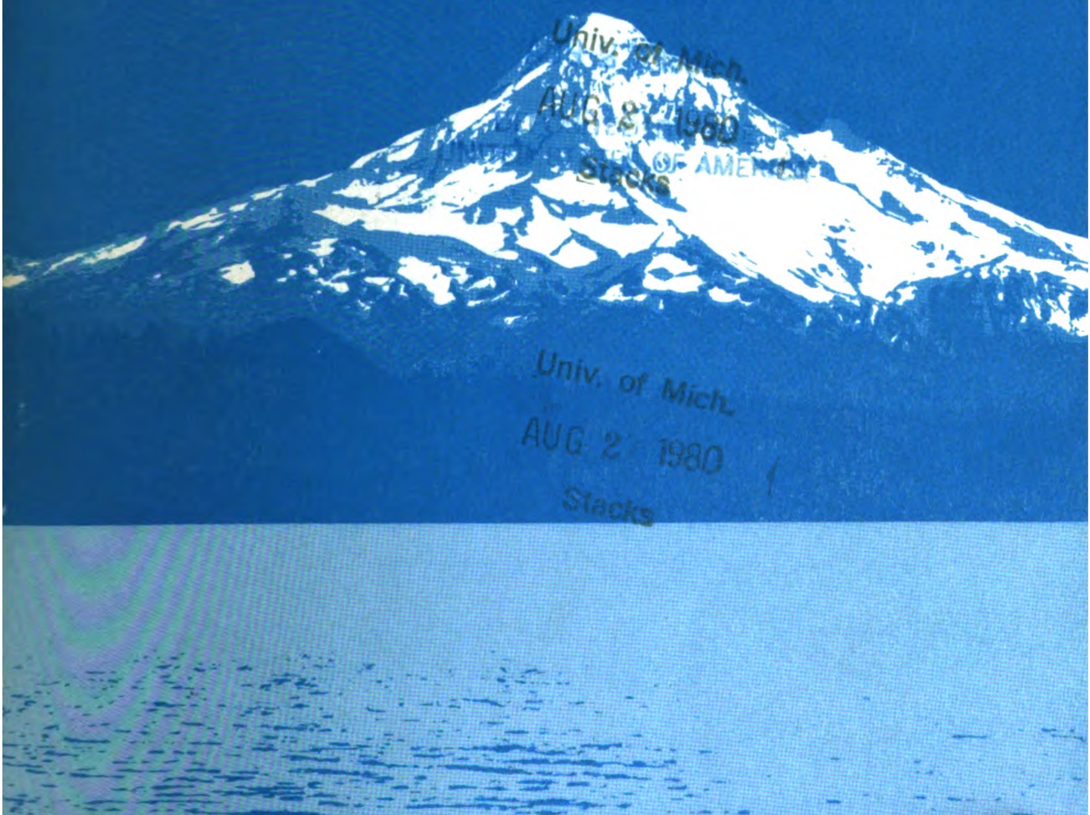
# RECENT ERUPTIVE HISTORY OF MOUNT HOOD, OREGON, AND POTENTIAL HAZARDS FROM FUTURE ERUPTIONS





GEOLOGICAL SURVEY BULLETIN 1492

# Recent Eruptive History of Mount Hood, Oregon, and Potential Hazards from Future Eruptions

**SOUTH SIDE OF MOUNT HOOD.** Dashed line outlines the fan of pyroclastic-flow deposits and mudflows formed 1,500–1,800 years ago. In the center of Mount Hood's crater is a remnant of a dome (arrow) that was erupted between 200 and 300 years ago.

# Recent Eruptive History of Mount Hood, Oregon, and Potential Hazards from Future Eruptions

By
Dwight R. Crandell

*An assessment of expectable kinds of future eruptions and their possible effects on human lives and property based on Mount Hood's eruptive behavior during the last 15,000 years*

**GEOLOGICAL SURVEY BULLETIN 1492**

United States Department of the Interior
CECIL D. ANDRUS, Secretary

Geological Survey
H. William Menard, Director

Library of Congress catalog-card No. 79-22249

U.S. GOVERNMENT PRINTING OFFICE : 1980

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock No. 024-001-0333-6-4

# CONTENTS

### Part II—Volcanic hazards assessment



### Appendices



# ILLUSTRATIONS

# TABLE

# UNITS OF MEASURE AND THEIR EQUIVALENTS

| *To convert metrics* | *Multiply by* | *To obtain* |
|---|---|---|
| Millimeters (mm) | 0.03937 | Inches (in.) |
| Centimeters (cm) | .3937 | Inches (in.) |
| Meters (m) | 3.28 | Feet (ft) |
| Kilometers (km) | .62 (about ⅔) | Miles (mi) |
| Cubic meters ($m^3$) | 35.31 | Cubic feet ($ft^3$) |
| Cubic kilometers ($km^3$) | .2399 (about ¼) | Cubic miles ($mi^3$) |
| Kilometers/hour (km/h) | .62 | Miles/hour (mi/h) |

# RECENT ERUPTIVE HISTORY OF MOUNT HOOD, OREGON, AND POTENTIAL HAZARDS FROM FUTURE ERUPTIONS

---

By DWIGHT R. CRANDELL

---

## ABSTRACT

Each of three major eruptive periods at Mount Hood (12,000–15,000(?), 1,500–1,800, and 200–300 years ago) produced dacite domes, pyroclastic flows, and mudflows, but virtually no pumice. Most of the fine lithic ash that mantles the slopes of the volcano and the adjacent mountains fell from ash clouds that accompanied the pyroclastic flows. Widely scattered pumice lapilli that are present at the ground surface on the south, east, and north sides of Mount Hood may have been erupted during the mid-1800's, when the last known activity of the volcano occurred.

The geologically recent history of Mount Hood suggests that the most likely eruptive event in the future will be the formation of another dome, probably within the present south-facing crater. The principal hazards that could accompany dome formation include pyroclastic flows and mudflows moving from the upper slopes of the volcano down the floors of valleys. Ash clouds which accompany pyroclastic flows may deposit as much as a meter of fine ash close to their source, and as much as 20 cm at a distance of 11 km downwind from the pyroclastic flows. Other hazards that could result from such eruptions include laterally directed explosive blasts that could propel rock fragments outward from the side of a dome at high speed, and toxic volcanic gases. The scarcity of pumiceous ash erupted during the last 15,000 years suggests that explosive pumice eruptions are not a major hazard at Mount Hood; thus, there seems to be little danger that such an eruption will significantly affect the Portland metropolitan area in the near future.

# INTRODUCTION

MOUNT HOOD volcano is situated at the crest of the Cascade Range 75 km east-southeast of Portland, Oreg., and 35 km south of the Columbia River (fig. 1). Because of the volcano's proximity to a large metropolitan area, future eruptions have been regarded as a potential threat by geologists and laypersons alike (McBirney, 1966, p. 25; Hammond, 1973; Harris, 1976, p. 264). The principal purpose of this report is to assess the nature and likelihood of this threat to communities around the volcano and to show areas of potential hazard when eruptions occur in the future. The volcanic-hazards map (pl. 1) that accompanies the report can be used for long-range land-use planning around the volcano and for preparing contingency plans for mitigating the effects of future eruptions.

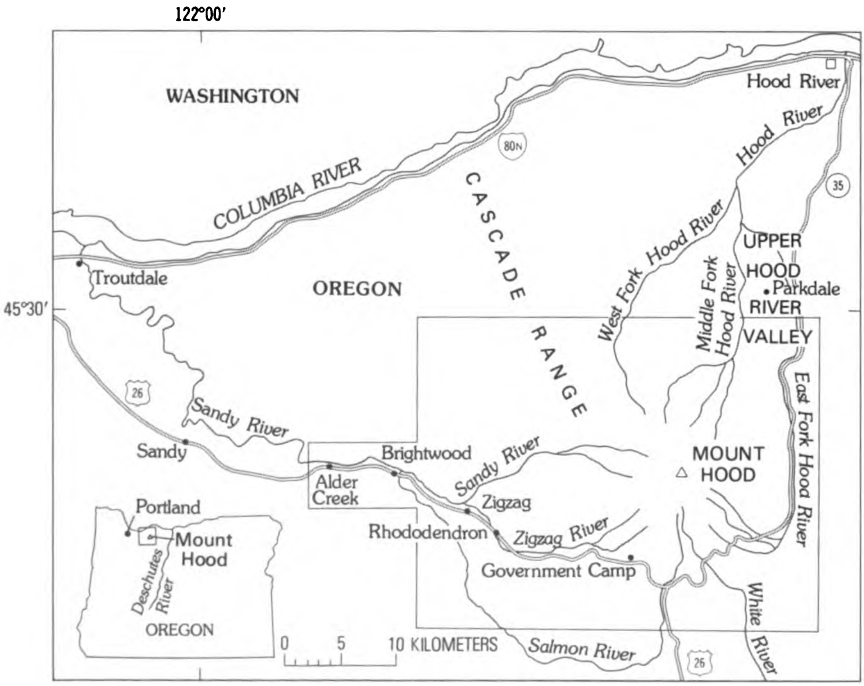



FIGURE 1.—Index map of the Mount Hood area. Rectangular area is shown in detail on plate 1.

If it is assumed that a volcano will continue to behave as it has in the past, a knowledge of its behavior pattern can provide a basis for predicting dangers that could result from future eruptions. Mount Hood lacks a well-documented record of historic eruptions. Thus, its past behavior must be analyzed by studying the geologic evidence of prehistoric eruptions. This is done by examining the rocks and unconsolidated volcanic deposits that resulted from those eruptions. From this examination the kinds, ages, and scales of activity that produced those deposits can be inferred, as well as the ways the eruptions affected the region around the volcano. Such an analysis is made here (part II; pl. 1) in order to anticipate the nature of future eruptions of Mount Hood and the areas they will affect.

The main body of this report is divided into two parts. Part I includes a description of the volcanic deposits that have been formed by eruptions during about the last 15,000 years and the kinds of eruptions that were responsible for these deposits. Part II is chiefly an assessment of volcanic hazards that could result from similar eruptions in the future. Some technical terms used in the report are explained in appendix A for readers who do not have a background in geology; these terms or variations of them are boldface the first time they appear in the following text. Readers lacking geologic background will benefit from reading appendix A before proceeding with the body of the report.

# Drainage

THE location and extent of areas affected by some kinds of volcanic phenomena are determined by topography; for example, **mudflows** and floods move along valley floors. Thus, the drainage pattern on and around the volcano is of great importance to the identification of potential hazard zones. Much of the south slope of Mount Hood is a broad, relatively smooth fan that slopes down to the area around Government Camp and is bounded on the east by the White and Salmon River valleys (fig. 1). The White River flows southward and southeastward through a virtually uninhabited region for many tens of kilometers and joins the Deschutes River, a tributary of the Columbia. The Salmon River takes a long circuitous course southwesterly, then northwesterly, through uninhabited country and finally joins the Sandy River. The west side of the fan is bounded by the Zigzag River, which, with its tributaries, drains the southwest slope of Mount Hood. The Zigzag River flows westward to join the Sandy River near the community of Zigzag. The Sandy heads on the west side of the volcano and flows westerly and northwesterly to its confluence with the Columbia River at Troutdale. The north and east sides of the volcano are drained by tributaries of the Hood River, which joins the Columbia at the city of Hood River. The largest concentration of population near Mount Hood is situated along the floors of the Zigzag and Sandy River valleys. These valley floors will be endangered by future eruptions that produce floods and mudflows on the west and south slopes of Mount Hood.

## Glaciation

THE extent of glaciers during the last major glaciation is pertinent to the eruptive history of Mount Hood because the presence of glacier ice was partly responsible for the distribution of volcanic deposits formed during the first eruptive period described in this report. Glacier extents shown in figure 2 are approximations based on widely scattered moraines and outcrops of glacial deposits; the downvalley extents shown for some glaciers may be in error by as much as several kilometers.

The last major advance of glaciers in Washington and British Columbia occurred during the Fraser Glaciation. This glaciation began some time before about 29,000 years ago and ended about 10,000 years ago (Armstrong and others, 1965; Armstrong and Clague, 1977). By comparison with glaciers in western Washington and British Columbia, those at Mount Hood probably reached their maximum downvalley extents by 18,000 years ago and then generally retreated until about 11,000 years ago. Glaciers in the mountains probably were not significantly larger by that time than they are today.

Deposits of the Fraser Glaciation at Mount Hood can be recognized by yellowish-brown soil oxidation and by a lack of

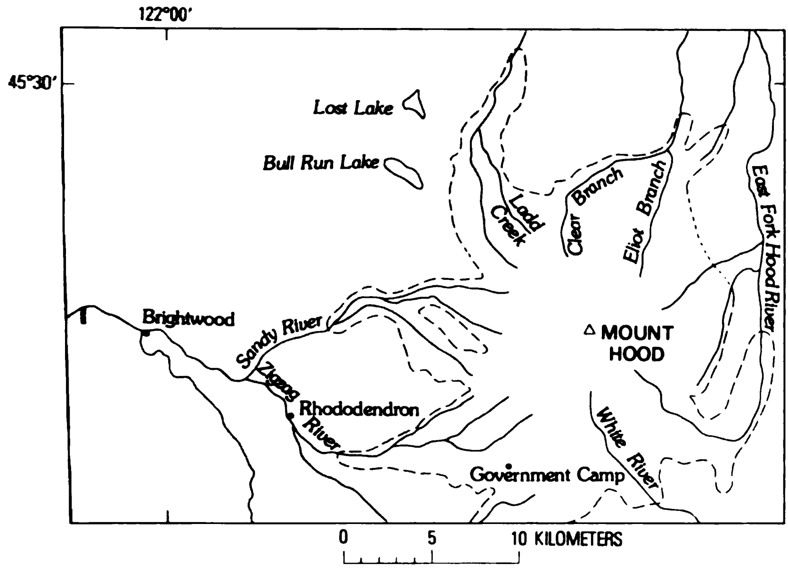



FIGURE 2.—Inferred extent of glaciers at Mount Hood during the Fraser Glaciation (dashed line) and probable maximum extent of glacier in the Sandy River valley during the next older glaciation (short heavy line).

appreciable weathering of stones in soil profiles. The thickness of the oxidized zone on till measured at 17 localities ranged from 35 to 90 cm and averaged 63 cm. These characteristics are similar to those of deposits of the first eruptive period (Polallie) described in this report. Some Polallie deposits, in fact, resemble those of glacial origin because of their coarse, poorly sorted, or unsorted texture. For example, deposits in roadcuts along U.S. Highway 26 about 3 km west of Government Camp resemble till, but they were formed by volcanic mudflows (fig. 3). Similar mudflow deposits on the northeast side of Mount Hood have obscured the extent of glacial deposits of Fraser age; thus, the extent of glaciers is not known in that area.

The average altitude[1] of north-facing cirques near Mount Hood is about 1,030 m (3,400 ft) in the areas north and northwest of the volcano, about 1,250 m (4,100 ft) south of the

[1] Altitudes are given in the inch-pound system because contours on the accompanying topographic map (pl. 1) are in feet.

FIGURE 3.—Bouldery volcanic mudflows of Polallie age in roadcut along U.S. Highway 26 about 3 km west of Government Camp. The largest boulder in the center of the photograph is about 1 m in length.

volcano, and about 1,370 m (4,500 ft) to the east. These cirque floors provide a crude measure of the altitude of areas of ice accumulation during the last glaciation; however, the lower limits of accumulation in areas outside cirques must have been higher because ice was not as protected from the sun there as in the cirques.

When Fraser glaciers were at their maximum extents, the northern slopes of Mount Hood probably were largely covered by ice at altitudes about 1,370 m (4,500 ft), and the southern slopes above perhaps 1,525–1,675 m (5,000–5,500 ft). Most north-facing glaciers today terminate at altitudes of 1,830–1,980 m (6,000–6,500 ft), and the lower limits of perennial snow on the south slope of the volcano seem to be at about 2,150 m (7,000 ft).

Deposits of one or more older glaciations have also been recognized at scattered localities in the Mount Hood area. One such deposit is till that forms a terminal moraine in the Sandy River valley near Brightwood (fig. 2); this moraine probably represents the farthest downvalley extent of a glacier during the glaciation that immediately preceded the Fraser Glaciation. Yellowish-brown soil oxidation extends to a depth of 1.5–2 m in the till, and stones in the soil profile have weathered rinds 1-2 mm thick. Glacial deposits in the Mount Rainier area of Washington that have similar weathering characteristics were assigned to the Hayden Creek Drift of the Salmon Springs Glaciation (Crandell and Miller, 1974).

Till thought to be of Hayden Creek age elsewhere in the Sandy River valley underlies a deposit of distinctive pumice that was erupted at Mount St. Helens in southern Washington between about 35,000 and 40,000 years ago (D. R. Mullineaux, oral commun., 1976). The best outcrop at which the relation of the till to the pumice can be seen is along a road to a rock quarry south of U.S. Highway 26 (appendix B, measured section 1).

At Bennett Pass, on the southeast side of Mount Hood, a large cut along State Highway 35 exposes three tills separated by yellowish-brown oxidized zones that constitute buried soils. The uppermost till forms a lateral moraine of Fraser age; the ages of the underlying tills are not known.

# Volcanic Rocks of Mount Hood

THE eruptive history of Mount Hood prior to about 15,000 years ago is chiefly recorded by the volcanic rocks that form the volcano. These rocks were described by Wise (1969), who divided them into four main groups. From oldest to youngest these are olivine andesite lava flows that form the base of the volcano, long flows of pyroxene andesite that extend down former canyons that headed on the volcano, flows of pyroxene andesite that form the part of the volcano above about 1,800 m (5,900 ft), and a remnant of a young dome of dacite that forms Crater Rock (Wise, 1969). The bulk of the volcano is made up of andesite in which the silicon dioxide ($SiO_2$) content ranges from about 57 to 61 percent. Rocks at Mount Hood that were described by Wise (1969) as dacites contain 62-63 percent $SiO_2$ and are limited to the products of the geologically most recent eruptions, including the deposits of the Polallie, Timberline, and Old Maid eruptive periods described in this report (appendix C). These dacites generally contain the ferromagnesian minerals hypersthene or hornblende, or both, and may include small amounts of augite. At some other volcanoes the presence or absence of these and other minerals has been used to distinguish volcanic deposits of different ages, but this was not found to be possible during the present study of Mount Hood.

Several volcanic vents on the lower flanks of Mount Hood or beyond its base have erupted olivine andesite lavas which are chemically similar to one another, but which do not seem to be genetically related to Mount Hood (Wise, 1969, p. 994, 999–1000). One vent is at The Pinnacle on the north flank of the volcano, another is near Cloud Cap Inn on the northeast flank (pl. 1), and a third lies in the valley of the Middle Fork Hood River 11.5 km northeast of the summit of Mount Hood. Wise believed that the lava flows from the vent at The Pinnacle were erupted before the Fraser Glaciation, but regarded those from the vent near Cloud Cap Inn as of post-Fraser age. Lava flows from The Pinnacle are locally overlain by glacial deposits of Fraser age. Soil profiles on deposits that overlie the lavas from the vent at Cloud Cap Inn indicate that these lavas, too, are pre-Fraser and probably are older than the Hayden Creek Drift.

The olivine andesite lava flow in the Middle Fork Hood River valley extends down the valley floor about 6 km from a vent south-southwest of Parkdale[2]. The flow is about 60 m thick (Wise, 1969) and as much as 1.2 km wide. Charcoal from a soil beneath the lava flow had a radiocarbon age of 6,890±130 years (Harris, 1973, p. 66–67; this report, table 1).

# Deposits of Old Mudflows and Pyroclastic Flows from Mount Hood

LARGE mudflows from Mount Hood moved westward down the Sandy River valley and northward into the Upper Hood River Valley many times prior to the Fraser Glaciation. The mudflows that extended into the eastern part of the Portland metropolitan area have been mapped and described by Trimble (1963). Some of these old mudflows are exposed at localities in the Sandy River valley between Brightwood and

[2]The length of the lava flow was mistakenly given as 6 miles by Wise (1969).

Alder Creek, and crop out in a roadcut along U.S. Highway 26 about 1.2 km west of Alder Creek. At this roadcut, the mudflow deposit is about 15 m thick and contains, in addition to fragments of basalt and pumice, a predominance of andesitic rocks derived from Mount Hood. The upper part of the mudflow is weathered to clay and is overlain by about 7 m of yellowish-brown loess. The extent of weathering at the top of the mudflow suggests that it is many tens of thousands of years old.

Old mudflows make up much of the southeast bank of the Sandy River in the west center of section 22, about 3 km east of Alder Creek. Wood from one of these mudflows about 3 m above the river had a radiocarbon age of more than 40,000 years (table 1). These deposits are part of a succession of mudflows that is deeply weathered at the top and forms a valley fill whose top is about 30 m above the Sandy River. The Sandy River glacier of Hayden Creek(?) age terminated less than 1 km east of the locality described above (fig. 2), where it built a moraine on top of the valley fill of mudflow deposits.

Old mudflows that resemble till are widespread in the Upper Hood River Valley, where they directly underlie the Parkdale soils deposit. (See p. 19.) The degree of weathering on these deposits suggests that they have a wide age range; some probably were formed during the nonglacial interval that preceded the Fraser Glaciation, and others are of pre-Hayden Creek age. Some of the deposits probably are of the same general age as the old mudflows west of Mount Hood.

Volcanic deposits of pre-Fraser age are well exposed at a locality near the top of the east canyon wall of Eliot Branch Hood River (fig. 2). The outcrop is located at about the 4,880-foot contour (see Cathedral Ridge 7½-minute quadrangle) at a point about 150 m north of a hairpin turn on the road to Cloud Cap Inn. Here, till of Fraser age, 23 m thick, overlies a pyroclastic-flow deposit about 12 m thick which has strong brown oxidation in the uppermost 1.5 m. Most stones in the oxidized zone have weathered rinds 1-2 mm thick. The deposit consists of unsorted and unstratified angular and subangular rock fragments as large as 1 m in diameter in a matrix of loose lithic ash; some rock fragments in the deposit are prismatically jointed. The pyroclastic-flow deposit overlies a mixture of nonvesicular rock fragments as much as 15 cm in diameter and lapilli of hypersthene-augite pumice in a matrix of lithic and pumiceous ash. The deposit is about 1.7 m thick and may have been formed by a mudflow. It overlies an andesite lava flow more than 50 m thick. These pre-Fraser deposits probably resulted from eruptive activity during the nonglacial interval that preceded the Fraser Glaciation.

# PART I
# RECENT ERUPTIVE PERIODS AND THEIR PRODUCTS

THREE PRINCIPAL ERUPTIVE PERIODS have occurred at Mount Hood since the maximum of the Fraser Glaciation. The first of these, which is referred to here as the Polallie eruptive period, is believed to have occurred when glaciers on Mount Hood were significantly larger than they are today. The second, which is referred to as the Timberline eruptive period, occurred between about 1,500 and 1,800 years ago; and the third, known as the Old Maid eruptive period, occurred between 200 and 300 years ago. In addition, a very small amount of pumice was ejected at Mount Hood some time during the last 200 years, perhaps in 1859 or 1865.

## Polallie Eruptive Period

THE oldest volcanic deposits described in this report were formed during the Polallie eruptive period, which is believed to have occurred some time between 12,000 and 15,000 years ago, during a late stage of the Fraser Glaciation. The deposits of Polallie age were formed chiefly by pyroclastic flows and mudflows and by ash clouds generated by pyroclastic flows.

## Deposits of Pyroclastic Flows and Mudflows

DEPOSITS of Polallie age occur on all sides of Mount Hood and consist chiefly of mixtures of coarse and fine nonvesicular rock debris that resulted from pyroclastic flows and mudflows. The rock debris probably avalanched from the flanks of dacite domes as the domes were being extruded at or near the summit of the volcano. The Polallie deposits typically occur in three different topographic positions: ridge top, valley side, and valley floor. The topographic positions of the ridge-top and valley-side deposits probably were determined by the presence and thickness of glacier ice in a given valley when the deposits were formed. Deposits accumulated on the tops of ridges when glacier ice still occupied the adjacent cirque or valley. The deposits on valley sides were formed adjacent to glaciers after the glaciers had shrunk in size, and the valley-floor deposits were laid down beyond the ends of valley glaciers during and following both of the earlier stages.

Rock fragments in deposits of Polallie age typically are light- to dark-gray dacite that contains hypersthene and variable amounts of hornblende or augite or both; olivine was not recognized in rocks of Polallie age. Hornblende was more abundant than hypersthene in only a few of the rock fragments that were sampled.

Typical Polallie deposits are exposed on the northeast side of Mount Hood in valley walls at the head of Polallie Creek 0.6–0.9 km southwest of Tilly Jane Guard Station (pl. 1). There, they consist of a succession at least 100 m thick of unsorted bouldery deposits of pyroclastic flows interbedded with mudflows of generally similar appearance. The deposits of pyroclastic flows can be recognized by the presence of reddish-gray tops 1–2 m thick and by the presence of prismatically jointed blocks of dacite. Blocks like these were sampled for chemical analysis from two deposits near the head of Polallie Creek (appendix C).

The Polallie deposits on the northeast side of Mount Hood form a broad triangular apron whose apex is on Cooper Spur, about 825 m (2,700 ft) below the summit of the volcano (pl. 1; fig. 4). The deposits underlie a broad sloping surface north of Cloud Cap Inn, extend northward between Tilly Jane Creek and Eliot Branch, and flank both sides of Polallie Creek


Cooper
Spur
Eliot Glacier
Stranahan Ridge

downstream to its mouth (pl. 1). They also form a fill, now mostly removed by erosion, in the valley of East Fork Hood River at and downstream from the mouth of Polallie Creek. This fill was responsible for forcing the East Fork against its east valley wall downstream from Cold Spring Creek (pl. 1). Temporary damming of the East Fork valley by the fill created one or more short-lived lakes which are represented by deposits of horizontally bedded fine sand and silt. The lake sediments are exposed in cuts along State Highway 35 near Sherwood Campground, where they are interbedded with thin mudflows that evidently moved southward, upstream, into the lake from the thickening Polallie fill. A few scattered lapilli of hyperstherne-augite pumice were noted in the lake sediments. The sediments were not seen beyond a few kilometers upstream from the campground.

Deposits of Polallie age were recognized downstream in the Upper Hood River Valley, where a gray, unweathered, sandy mudflow forms a terrace about 20 m above the East Fork Hood River in section 5, about 2 km southeast of Parkdale. This deposit is overlain by the Parkdale soils deposit (p. 21). Seven kilometers farther downstream, correlative gray cobble to boulder gravel of Polallie age is oxidized to a depth of nearly 1 m where the Parkdale deposit is absent.

At Cooper Spur, the presence of the broad apron of loose rock debris that extends as high as 2,600 m (8,500 ft)—in an area on the flank of Mount Hood that should have been covered by ice at the maximum of the Fraser Glaciation (fig. 2)—suggests that the debris was deposited some time after that ice disappeared. At a point about 3 km west-southwest of Tilly Jane Guard Station, the south edge of the Polallie deposits is flanked by a lateral moraine formed at the north margin of Newton Clark Glacier during a late stage of the Fraser Glaciation; and the Polallie deposits are not present south of the moraine. These relations suggest that deposition of rock debris south of the moraine was prevented by the presence of the glacier, which was larger than it is now and which subsequently retreated and built the moraine. The

◁ FIGURE 4.—North side of Mount Hood. Remnants of fans of coarse pyroclastic flows and mudflows of Polallie age underlie Cooper Spur and Stranahan Ridge.

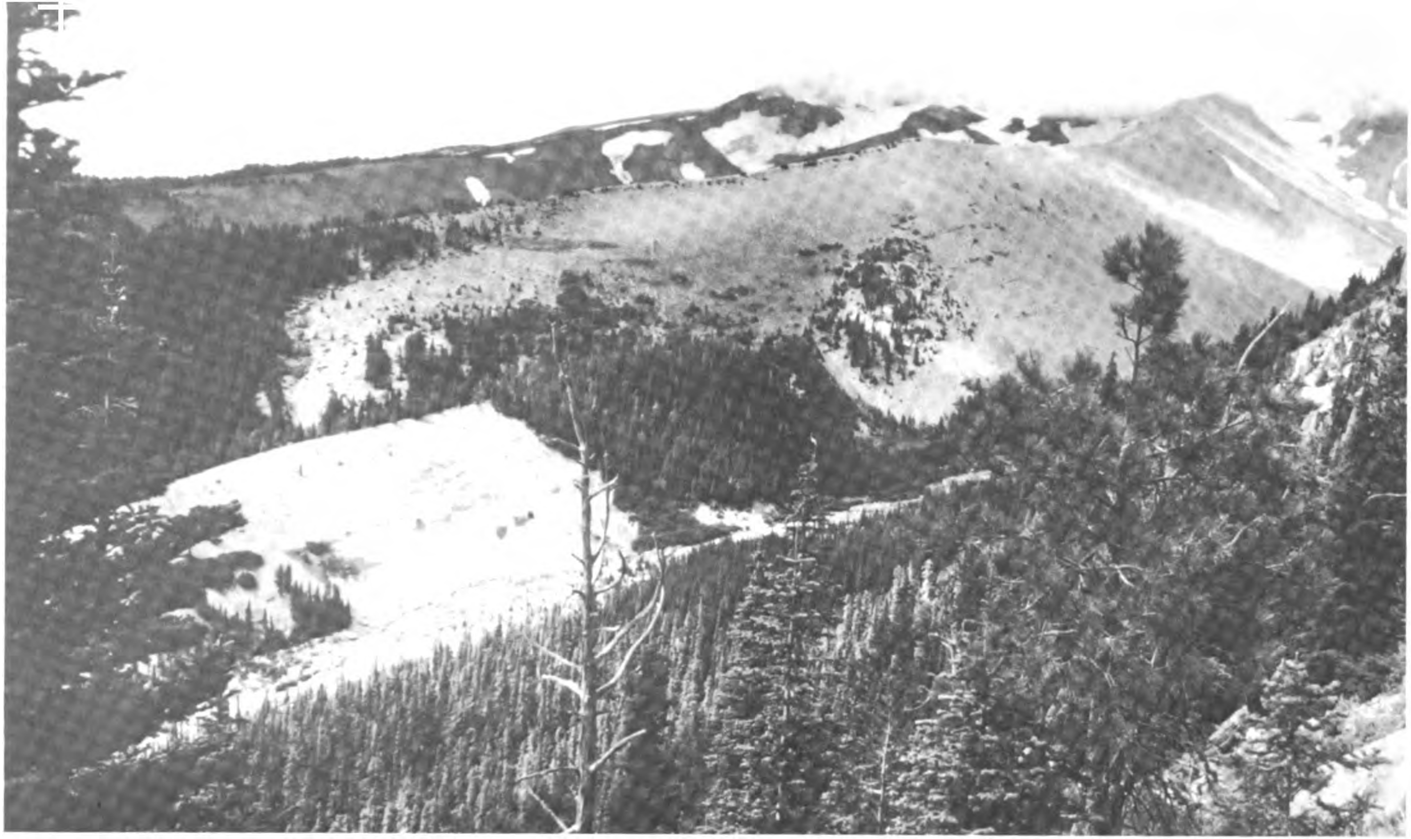


FIGURE 5.—Valley of Newton Creek on southeast side of Mount Hood. Deposits of pyroclastic flows and mudflows of Polallie age form the two light-colored fills in the center of the photograph. The tops of these fills are at heights of about 85 and 220 m, respectively, above Newton Creek. The ridge on the skyline consists of lava flows from Mount Hood that are locally overlain by Polallie deposits.

western limit of the Polallie deposits likewise was determined by Eliot Glacier when it was substantially larger than it is now.

Deposits of rock debris formed during the Polallie eruptive period on other sides of the volcano represent several stages of valley filling that were separated by times of erosion. For example, a high sharp-crested ridge that separates the heads of Newton and Clark Creeks (pl. 1) on the southeast side of the volcano is underlain by rock debris that was deposited by pyroclastic flows and mudflows. Similar deposits within the Newton Creek valley are present in remnants of an intermediate fill whose top is about 100 m lower than the top of the sharp-crested ridge (fig. 5); this intermediate fill was formed after the high fill had been deeply eroded. The lowest and youngest deposits of Polallie age form the flat floor of the valley followed by Newton and Clark Creeks eastward beyond the base of the volcano. At its head, this flat-floored valley lies about 60 m below the top of the intermediate fill terrace. The youngest Polallie deposits consist only of mudflows; these probably were derived chiefly or wholly from the two older deposits as they were being eroded. All three fill deposits, however, have similar soil profiles and thus were formed at roughly the same time, although together they may have been deposited over a period of a thousand years or more.

A similar succession of fill deposits is present at the head of White River on the south side of the volcano (fig. 6). Pyroclastic-flow deposits of Polallie age underlie the high divide that is east of White River and northwest of Mount Hood Meadows (pl. 1). The floor of the basin in which Mount Hood Meadows is situated is underlain by glacially eroded rock and glacial deposits; deposits of Polallie age are lacking, even though they underlie the ridge at the head of the basin, 180–660 m higher. Evidently, the basin was largely filled with glacier ice and thus was shielded from pyroclastic flows and mudflows during the Polallie eruptive period. On the west side of the high ridge, two valley fills adjacent to White River are both lower than the deposit that forms the ridge top, one fill is about 70 m lower than the ridge top, and the other is 160 m lower. The deposits that underlie the high ridge evidently were formed early in the Polallie eruptive period when the White River glacier was much thicker and wider than now,

and when it extended at least 3 km farther downvalley. The two lower deposits of Polallie age were formed after the glacier had retreated and become thinner and narrower. These deposits can be seen overlying glacial deposits in a south-facing cliff 1.7 km directly east of Timberline Lodge. The lack of a soil at the top of the glacial deposits indicates that they were buried by the Polallie deposits soon after the glacier retreated.

Wise (1966, fig. 3; 1968, fig. 16) recognized the multiple origin of the deposits adjacent to the White River, but he regarded the ridge-top deposits as glacial drift and thought that the intermediate deposits were formed during the 1,500- to 1,800-year-old Timberline eruptive period. However, the presence of relatively thick soil profiles on the two lower deposits indicates that they are older than the Timberline period and are of approximately the same age as the Polallie deposits that form the high ridge. The lowest fill in the White River valley was thought by Wise (1966, p. 17) to have resulted from a "later surge of dome activity"; these deposits are now known to consist of mudflows and pyroclastic-flow deposits 200–300 years old (p. 35). Deposits of Timberline age evidently are not present within the White River valley.

Mudflows and pyroclastic-flow deposits of Polallie age underlie much of the area between the White River and Zigzag Canyon. They are exposed in many roadcuts along both the old road and the new highway between Government Camp and Timberline Lodge—and along U.S. Highway 26 west of Government Camp (fig. 3). They crop out beneath younger deposits in Little Zigzag Canyon about 2 km downvalley from the Skyline Trail and are especially well exposed in the walls of Zigzag Canyon where it is crossed by that trail.

On the west side of Mount Hood, deposits of Polallie age crop out on both sides of the Muddy Fork valley along a trail (not shown on pl. 1) that extends from Ramona Falls to Bald

◁ FIGURE 6.—West wall of White River canyon (left foreground). Deposits of Polallie age underlie the ridge on the right skyline and the flat-topped fill at right center of the photograph, and crop out in the canyon wall in the foreground. The prismatically jointed block indicated by the arrow is about 1 m in diameter.

Mountain. Some of these deposits are as much as 300 m above the valley floor, but there is no evidence, in the form of flat-topped terraces, that the deposits ever filled the valley from side to side to a depth of 300 m. Instead, they seem to be veneers on the valley walls and probably were formed when the Sandy Glacier occupied the Muddy Fork valley. Successive deposits probably accumulated as pyroclastic flows and mudflows moved downslope between the margin of the glacier and the valley wall as the glacier slowly shrank. The volume of the Polallie deposits in the Muddy Fork valley is a very small fraction of the volume of similar deposits in valleys on the northeast, southeast, and south sides of the volcano.

Other deposits of Polallie age were noted on the ridge west of Wiyeast Basin, on Barrett Spur up to an altitude of about 2,210 m (7,300 ft), and on Stranahan Ridge north of Timberline Trail (fig. 4). In addition, a small outcrop of Polallie deposits contains prismatically jointed blocks at the place Timberline Trail crosses the east fork of Compass Creek. With this exception, the deposits of Polallie age on the north side of the volcano all occur on ridge tops and are absent from the floors of cirques.

Wise (1969, pl. 1) showed the deposits that are here assigned to the Polallie eruptive period on his geologic map of the Mount Hood area and referred to them as "Mt. Hood clastic debris, largely pyroclastic but on surface much post-glacial redistributed detritus." The Polallie deposits described in the present report are less extensive than those shown by Wise, whose map unit includes the deposits of the Timberline eruptive period, locally those of the Old Maid eruptive period, some glacial deposits of Fraser age, and some unconsolidated deposits of pre-Fraser age.

## Ash-Cloud Deposits and the Parkdale Soils

FINE yellowish-brown lithic ash as much as half a meter thick can be found at many localities east and northeast of the volcano. At some places the ash is present on top of mudflow and pyroclastic-flow deposits of Polallie age, as in the area southwest of Tilly Jane Guard Station (fig. 7), so it evidently is no older than the Polallie eruptive period.

A similar deposit of yellowish-brown ash is present in the Upper Hood River Valley 15–20 km north-northeast of Mount Hood. This deposit, which is known as the Parkdale soils (Harris, 1973), mantles flat to gently rolling, north-sloping surfaces formed by alluvium and mudflows of Pleistocene age derived from Mount Hood. The Parkdale soils thin and pinch out near the east side of the Upper Hood River Valley and also disappear toward the north end of the valley. The deposit is present west of the valley, but its extent in that direction has not been determined. The deposit generally thickens southward; its maximum reported thickness is 4.1 m at a point in the Upper Hood River Valley about 1 km northwest of the community of Parkdale (Harris, 1973, p. 30–33). This site is about 18 km north-northeast of the summit of Mount Hood; Harris (1973, p. 42) reported that the deposit is not present on Middle Mountain, about 6 km north of Parkdale.

Typically, 80–85 percent of the deposit is of sand and silt size (0.002–2 mm). Harris (1973) noted that the sand-size fraction of the Parkdale consists chiefly of feldspars, particles of volcanic rock, and products of weathering; and he reported (p. 107) that ferromagnesian minerals present include pyroxenes and hornblende. A very small amount of pumice and glass was present in the samples studied by Harris.

According to Harris (1953, p. 24), the Parkdale also contains "shot", which consists of pellets, commonly of iron oxides, produced by soil-forming processes. He described the "shot" as being concentrated in the uppermost 20–30 cm, but occurring throughout the Parkdale. The pellets Harris referred to range in diameter from 2–10 mm and consist of aggregates of sand and silt-sized ash. They are made up of particles that include mineral fragments, mineral crystals, rock, pumice, and charcoal. Most pellets lack structure but faint concentric layers can be seen in others. Some pellets are irregular and others are of spherical shape. Some spherical pellets have hollow cores a few millimeters in diameter. The pellets resemble accretionary ash and lapilli which typically are formed when moisture condenses in an eruption cloud or when rain falls through a cloud of ash and causes particles to adhere to one another.

A radiocarbon age of 12,270±190 years (table 1) was determined from a composite sample of charcoal particles taken from a zone 1.7–2.1 m below the surface of the Parkdale soils deposit (Harris, 1973, p. 65). The deposit at the sample locality is about 2 m thick and overlies coarse mudflow deposits in which some boulders are as much as 50 cm in diameter. I collected large fragments of charcoal from a horizon about 0.8 m below the top of the Parkdale at the same locality; these had a radiocarbon age of 4,320±200 years (radiocarbon sample W–3731). The reason for this discrepancy in age is not known. Harris noted that the Parkdale deposit underlies a lava flow west of Parkdale. Charcoal that he collected from the deposit at the base of the flow, which presumably was charred by the lava, had a radiocarbon age of 6,890±130 years (Harris, 1973, p. 65).

The age relation of the Parkdale soils to deposits of Polallie age is illustrated at a roadcut in the Upper Hood River Valley in the center of the NE¼ sec. 5, T. 1 S., R. 10 E. (Hood River 15-minute quadrangle). The yellowish-brown Parkdale deposit at this locality is about 1.6 m thick and directly overlies a gray, unweathered, sandy mudflow that forms a terrace on the west side of the East Fork Hood River and is about 20 m higher than the adjacent flood plain. (See p. 13.) The absence of a soil between the deposits indicates that there was not an appreciable time interval between deposition of the Polallie mudflow and the overlying Parkdale.

One of Harris' principal objectives in his comprehensive study of the Parkdale soils deposit was to determine its origin, which evidently has been the subject of some controversy (Harris, 1973, p. 13–14). Because of the very small amount of volcanic glass in the deposit, Harris concluded that the Parkdale is not volcanic ash. He also noted that the mineralogy of the deposit is different from that of wind-deposited material east of the Hood River Valley and inferred that the Parkdale is not a loess. The predominant volcanic

◁ FIGURE 7.—Ash-cloud deposits of Polallie age (yellowish brown) underlie those of Timberline age (gray and reddish gray) at the top of the north canyon wall of Polallie Creek 0.6 km southwest of Tilly Jane Guard Station. These deposits overlie pyroclastic-flow deposits and mudflows of Polallie age. Handle of shovel is about 50 cm long.

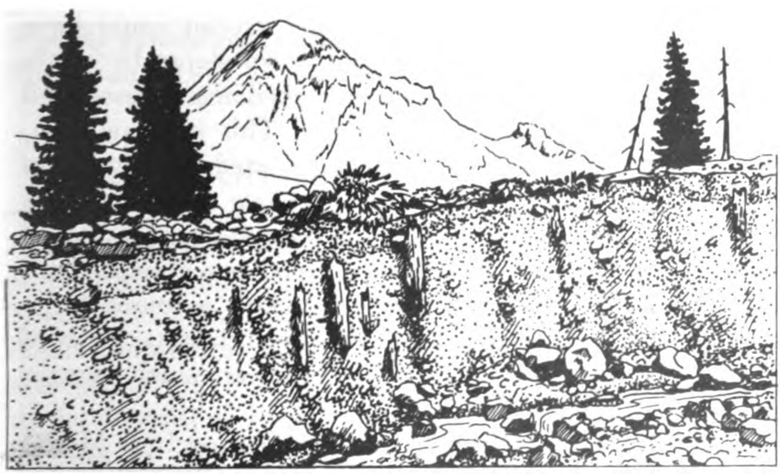
TABLE 1.—*Radiocarbon dates from samples of wood and charcoal in volcanic deposits in the Mount Hood area*

[Dates with W sample numbers were determined by Meyer Rubin and Eliot Spiker in the radiocarbon laboratory of the U.S. Geological Survey. Dates for samples M-898, M-899, and M-900 were determined at the University of Michigan (Lawrence and Lawrence, 1959), and two other samples were dated by Teledyne Isotopes, Inc. Harris, 1973). Symbols: <, less than; >, greater than]

| Date (radiocarbon years before 1950) | Laboratory number | Kinds of samples, stratigraphic position, and location |
|---|---|---|
| <200 | W-3744 | Charcoal in forest duff between uppermost two mudflows in roadcut 0.5 km north of Zigzag, in low bluff near confluence of Zigzag and Sandy Rivers (see appendix B, measured section 2). |
| <250 | W-601 and W-661 | Wood samples from stumps buried by mudflows in Sandy River valley at Old Maid Flat. |
| 220±150 | W-3629 | Charcoal from deposit of hot mudflow in north bank of Sandy River about 2 km northwest of Upper Sandy Guard Station. |
| 250±150 | W-899 | Wood from upright stump buried by mudflows in east bank of White River about 0.8 km east of Timberline Lodge. |
| 260±150 | W-3417 | Charcoal from lower of two pyroclastic-flow deposits in west bank of White River about 1 km upstream from State Highway 35. |
| 920±150 | W-900 | Wood from upright stump buried by mudflows in north bank of Zigzag River at Twin Bridges Campground. |
| 1,530±200 | W-3407 | Wood from log incorporated in mudflow deposits near base of south bank of Sandy River 0.2 km southwest of Upper Sandy Guard Station. |
| 1,610±200 | W-3409 | Charcoal at base of ash-cloud deposits in roadcut about 2 km northeast of Government Camp. |

TABLE 1.—*Radiocarbon dates from samples of wood and charcoal in volcanic deposits in the Mount Hood area*—Continued

| Date (radiocarbon years before 1950) | Laboratory number | Kinds of samples, stratigraphic position, and location |
|---|---|---|
| 1,670±200 | W-898 | Wood from mudflow about 0.5 km south of Government Camp |
| 1,780±200 | W-3742 | Wood from mudflow in south bank of Sandy River 1 km west-northwest of Zigzag (see appendix B, measured section 3). |
| 4,320±200 | W-3731 | Charcoal from depth of 0.8 below top of Parkdale soils deposit in roadcut 2.2 km west-northwest of Parkdale. |
| 6,890±130 | Teledyne Isotopes | Charcoal from beneath lava flow about 2.5 km west-southwest of Parkdale. |
| 12,270±190 | Teledyne Isotopes | Charcoal from zone 1.7–2.1 m below top of Parkdale soils deposit in roadcut 2.2 km west-northwest of Parkdale. |
| >40,000 | W-3740 | Wood from mudflow about 1 m above river level in southeast bank of Sandy River about 4 km west of Brightwood. |



Tree trunks buried in mudflow.

lithology of the Parkdale led Harris to conclude that the deposit was formed by a volcanic mudflow from Mount Hood; and, in order to explain the fine texture of the deposit, he suggested that the mudflow was derived from texturally similar material on the flanks of the volcano.

There are some objections to the suggestion that the Parkdale originated as a volcanic mudflow. One is its vertical distribution. If the Parkdale was formed by a mudflow, it should be thicker in the low areas of a valley and thinner or absent in high areas. This relation is not present. Moreover, Harris (1973, p. 42–45) found deposits similar to the Parkdale west of the Upper Hood River Valley on a mountainside at least 200 m higher than the valley. To attain this height, the entire valley would have had to have been filled temporarily by a mudflow at least 200 m deep. This interpretation seemingly is inconsistent with the small range in thickness of the Parkdale deposit across the flat and gently rolling surfaces of the Upper Hood River Valley. Another objection to a mudflow origin is the fine-grained, generally well sorted nature of the Parkdale deposit. Even though mudflows on low gradients typically are incapable of eroding surfaces over which they move (Crandell, 1971), it seems unlikely that large volumes of fine material could have moved down the steep-gradient valleys from Mount Hood without incorporating large amounts of coarse stream gravel. With respect to a possible source, Harris (p. 57) implied that the hypothetical mudflow responsible for the Parkdale deposit could have originated in "Debris * * * shaken down slopes by earthquakes, volcanic eruptions, or other phenomena associated with volcanoes and volcanic activity." This interpretation, however, is inconsistent with the well-sorted character and predominantly fine texture of the Parkdale deposit. Harris (p. 57–59, 161) described a deposit of fine ash near Cloud Cap Inn on the northeast side of Mount Hood as a possible remnant of material that could have provided a source for a mudflow; however, the deposit he described consists chiefly of ash-cloud deposits of Timberline age which are much younger than the Parkdale deposit.

Harris (1973, p. 62) cited the Osceola Mudflow from Mount Rainier as an example of the ability of mudflows to carry material long distances. The Osceola contains abundant material that evidently was picked up as the mudflow moved downvalley from Mount Rainier. The deposit is poorly sorted and contains a wide range of sizes of material at a distance of as much as 100 km from the volcano; thus, the Osceola Mudflow is in no way similar to the Parkdale deposit. Despite Harris' conclusion to the contrary, the size range and areal distribution of the Parkdale deposit seem to be more consistent with transportation and deposition by wind than by a volcanic mudflow.

It has been proposed that the Parkdale soils deposit represents, for the most part, the fallout from ash clouds generated by pyroclastic flows moving down the slopes of Mount Hood (Crandell and Rubin, 1977). If the Parkdale originated in this way, strong winds blowing from the volcano toward the Upper Hood River Valley could have caused the limited lateral distribution of the deposit. In addition, the limited northward extent of the deposit could be explained by the restriction of the ash clouds to relatively low altitudes, so that the ash fell relatively close to its source. The limited extent and excessive thickness of the deposit in the Upper Hood River Valley also could have resulted from locally heavy rainfall which caused most of the ash to be deposited in a relatively small area. The presence in the Parkdale of pellets inferred to be accretionary ash and lapilli seems to support this hypothesis. The abundance of lithic material and scarcity of glass noted by Harris are common characteristics of ash-cloud deposits generated by lithic pyroclastic flows (Crandell and Mullineaux, 1973, p. A6).

## Age and Origin of the Polallie Deposits

THE age of the Polallie deposits is suggested by their degree of weathering and by their inferred relation to glaciers on Mount Hood. The thickness of the oxidized zone measured on Polallie deposits at 16 localities ranged from 35 to 85 cm and averaged 60 cm. This similarity to the depth of oxidation on glacial deposits of Fraser age (p. 5) implies that the Polallie deposits are no younger than the Fraser Glaciation; it also provides additional evidence that they were formed during a late stage of the glaciation rather than at some later time. The inferred relation of the Polallie deposits to glaciers on the flanks of Mount Hood suggests that the deposits were formed after glaciers had withdrawn to the flanks of the volcano following their maximum stand about 18,000 years ago (p. 4); however, the glaciers were still larger than they are today. In the absence of radiometric dates on the Polallie deposits, the best estimate that can be made with the evidence available is that the deposits were formed at some time between about 15,000 and 12,000 years ago.

Evidence described previously indicates that a succession of domes of hypersthene-hornblende dacite was formed at or near the summit of Mount Hood during the Polallie eruptive period. Avalanches of hot rock debris from the flanks of these domes produced pyroclastic flows on all sides of the volcano at a time when glaciers were still substantially larger than they are today. Mudflows generated by the remobilization of debris in pyroclastic-flow deposits probably extended tens of kilometers from the volcano down the valley floors of the East Fork Hood River as well as the White, Salmon, and Sandy Rivers. At the end of the eruptive period, Mount Hood probably lay buried by aprons of rubble; beyond the volcano these aprons merged with long unbroken fills that extended down each major valley. The lengths of these fills are not known, but one north of the volcano reached at least as far as the Upper Hood River Valley and may even have extended to the Columbia River.

Clouds of ash generated by pyroclastic flows on the volcano during at least part of the Polallie eruptive period deposited fine ash north of Mount Hood and probably as far north as the Upper Hood River Valley to form the Parkdale soils deposit.

## Timberline Eruptive Period

DEPOSITS of the Timberline eruptive period were formed by pyroclastic flows and mudflows between about 1,500 and 1,800 years ago and by ash clouds that accompanied the pyroclastic flows. The pyroclastic-flow deposits are restricted to the area between the Sandy and White Rivers, but mudflows extend down the Sandy River to its mouth.

## Deposits of Pyroclastic Flows and Mudflows

TYPICAL Timberline deposits are exposed in Little Zigzag Canyon where Skyline Trail crosses the canyon (fig. 8). There, in the sides of the canyon, a series of bouldery mudflows and pyroclastic-flow deposits, each a meter to several meters thick, can be seen interbedded with lenticular layers of fine to coarse lithic ash a few centimeters to several tens of centimeters thick.

Rock fragments in the Timberline deposits consist chiefly of gray and red dacite that contains hypersthene and hornblende in variable proporitons. A chemical analysis of a sample of this rock, taken from a prismatically jointed block along Skyline Trail just east of Little Zigzag Canyon, is given in appendix C. The overall color of the Timberline deposits is generally redder than that of either the Polallie or Old Maid deposits. The depth of yellowish-brown soil oxidation on the Timberline deposits ranges from 20 to 40 cm and averages between 25 and 30 cm.

The easternmost valley on Mount Hood in which mudflows of Timberline age were recognized is that of the Salmon River. East of Timberline Lodge the deposits can be seen burying a soil-oxidation zone at the top of Polallie deposits. Mudflows of Timberline age were noted in the Salmon River valley near the intersection of U.S. Highway 26 and State Highway 35, but were not traced farther downvalley.

A thick succession of mudflows forms a terrace whose top is about 60 m above the Sandy River southwest of the Upper Sandy Guard Station (fig. 9). The height of this terrace decrease downstream, and the mudflows are buried by deposits of Old Maid age (p. 35) beyond a point about 1 km northwest of the guard station. Logs as much as 1 m in diameter are present in a mudflow near the base of the valley wall opposite the guard station. Wood from one of these logs had a radiocarbon age of 1,530±200 years (table 1).

Deposits of Timberline age underlie much of the south flank of the volcano north and west of Timberline Lodge and extend downslope to the base of Multorpor Mountain. Prismatically jointed blocks of dacite are abundant on the broad fan upslope from, and west of, Timberline Lodge (fig. 10). Wood from a mudflow exposed along a drainage ditch in

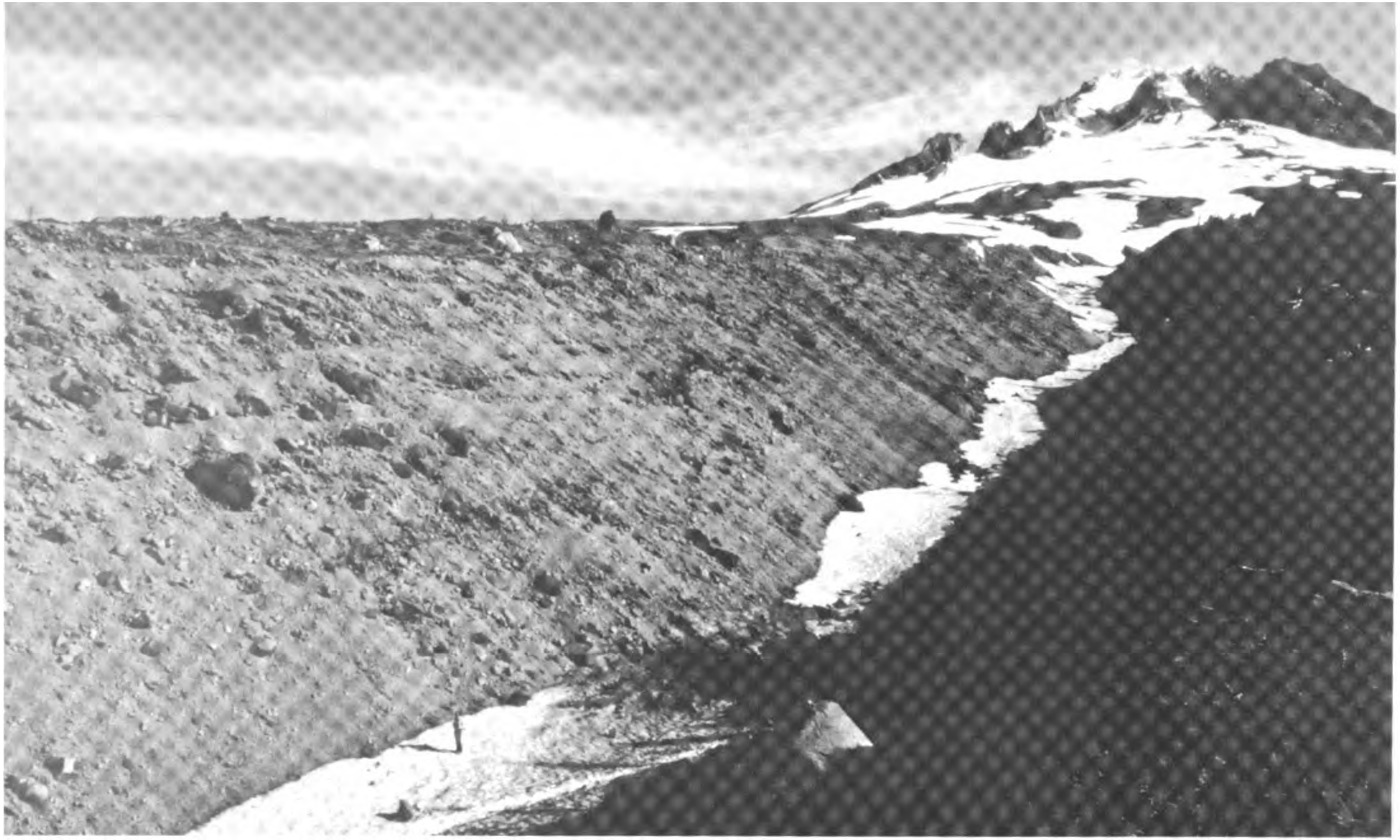


FIGURE 8.—Deposits of pyroclastic flows and mudflows of Timberline age exposed on west side of Little Zigzag Canyon near Skyline Trail. Man standing on snow at bottom of photograph shows scale.

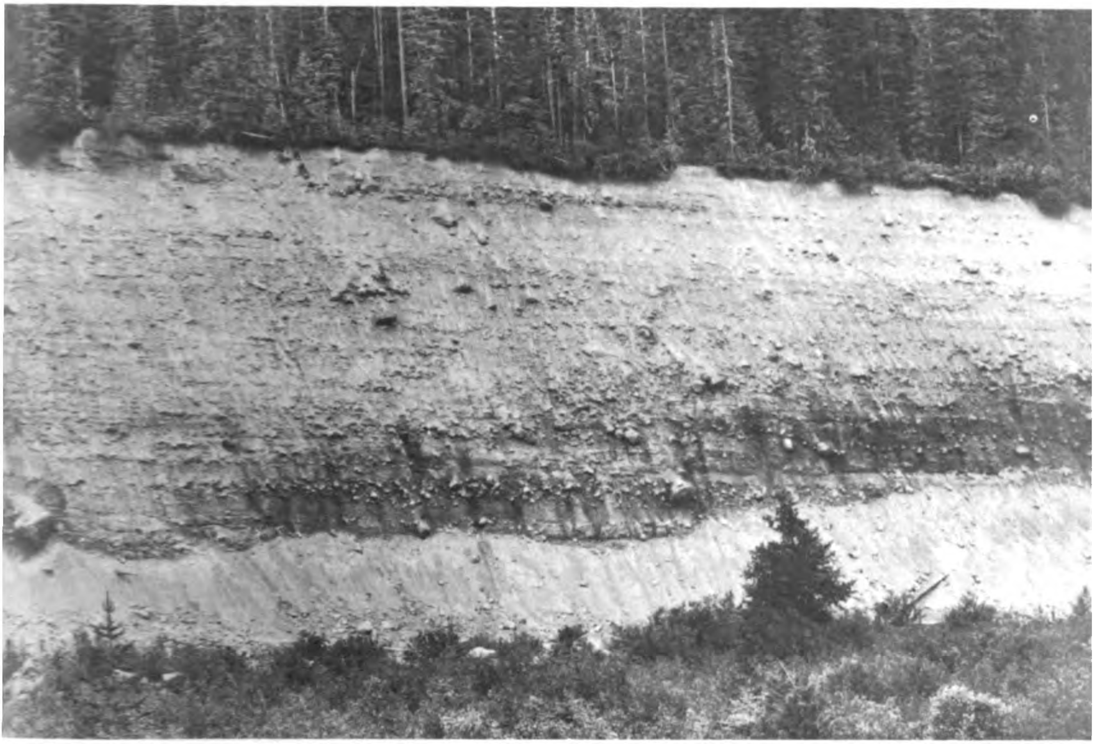


FIGURE 9.—Fill terrace formed by mudflows of Timberline age in the Sandy River valley near the Upper Sandy Guard Station. The height of the terrace is about 60 m.

the meadow south of Government Camp, near the southern margin of the fan, had a radiocarbon age of 1,670±200 years (table 1; Lawrence and Lawrence, 1959). Mudflows that moved down Zigzag and Little Zigzag Canyons underlie the floor of the Zigzag River valley from Twin Bridges Campground westward beyond the community of Zigzag. Wood from a log in a mudflow exposed in the south bank of the Sandy River about 1 km west-northwest of Zigzag had a radiocarbon age of 1,780±200 years. (See appendix B, measured section 3.) The mudflow is about 5 m thick and is overlain by two other mudflows each about 1 m thick. The entire valley floor between the Sandy River and the Salmon River is underlain by mudflow deposits, but some of these are at least as old as the Polallie eruptive period. Downstream from the mouth of the Salmon River, mudflows of Timberline

age crop out intermittently along the Sandy River valley as far as Troutdale, at the mouth of the river.

The mudflows of Timberline age near Troutdale are of special interest because of their downstream distance of about 80 km from the volcano. The deposits are exposed in the front of a terrace on the west bank of the Sandy River near a sewage-disposal plant, about 150 m south of Interstate Highway 80. The lowest mudflow is 1.5 m thick and consists of rock fragments as much as 5 cm in diameter in a silty sand matrix. It overlies river-deposited sand and gravel that probably extends below river level. The mudflow is overlain by about 4 cm of silty sand, above which is a mudflow about 0.6 m thick that contains rock fragments as large as about 1 cm in diameter in a silty sand matrix. These poorly sorted deposits are overlain by 1.3 m of sand that forms the top of the terrace about 6.5 m above the Sandy River.

## Ash-Cloud Deposits

FINE ash of Timberline age blankets much of the lower slopes of the volcano. Most of it consists of fine particles of rock, feldspar, and glass; ferromagnesian minerals in the ash are mainly hypersthene and hornblende, rarely accompanied by augite. The origin of the ash is inferred from an exposure at a locality about 2 km northeast of Government Camp. There, a cut along the old road to Timberline Lodge exposes about 1 m of ash on top of mudflows of Polallie age (fig. 11). A sample of charcoal taken from the contact between the ash and the mudflows had a radiocarbon age of 1,610±200 years. Although the deposit is not stratified, the upper 50 cm is reddish-gray ash that contains irregular masses of texturally similar gray ash. The lower half of the deposit is gray to yellowish gray. These colors probably are the original colors of the ash, or were formed by oxidation soon after the ash was deposited, and are not related to subsequent weathering. The outcrop is about 30 m east of the east margin of coarse mudflows and pyroclastic-flow deposits of Timberline age, on

◁ FIGURE 10.—Large prismatically jointed block of dacite in fan deposits of Timberline age upslope from Timberline Lodge. Ice axe is about 80 cm long.

which the ash is absent. Because of these relations and the radiocarbon age at the base of the ash, the ash is inferred to be genetically related to pyroclastic flows of Timberline age and to represent airborne material that was carried downwind from those flows.

Ash deposits east and northeast of the locality just described are correlated by the presence of reddish-gray and yellowish-gray material, by stratigraphic relations to overlying light-gray ash inferred to be of Old Maid age, and, locally, by their relation to underlying Mazama ash, which originated in eruptions at Crater Lake, Oreg., about 6,600 years ago. The lack of well-defined marker beds at many localities makes it difficult to distinguish ash of Timberline age from lithic ash that may be older. In general, however, ash thought to be of Timberline age generally is 15–60 cm thick on the south, east, and northeast sides of the volcano at distances of as much as 10 km from the summit. West of Mount Hood, 20 cm of Timberline ash was noted on Yokum Ridge at a distance of 4 km from the volcano's summit.

Lapilli of white hypersthene-hornblende pumice were noted in the ash of Timberline age at Hood River Meadows, at Mount Hood Meadows, near Sherwood Campground in the East Fork Hood River valley, and near Cloud Cap Inn. Nowhere do the pumice lapilli form a continuous layer. At Mount Hood Meadows the lapilli are as much as 4 cm in diameter and occur within the lower 10 cm of the ash deposit which is about 40 cm thick. (See appendix B, measured seciton 4.) The presence of these scattered pumice lapilli in the ash-cloud deposits suggests that a pumice eruption of very small volume occurred during a period that was otherwise characterized by the eruption of nonvesicular dacite.

Within a few hundred meters of the edges of deep canyons on the flank of Mount Hood, ash of Timberline age is underlain and overlain by loose, brown, fine to medium sand as

---

◁ FIGURE 11.—Light-reddish-gray ash-cloud deposit of Timberline age overlying dark-yellowish-brown mudflow of Polallie age at a roadcut about 2 km northeast of Government Camp. Dashed line marks the approximate base of the ash-cloud deposit. The tape measure is resting on a boulder in the mudflow. Charcoal from the base of the ash-cloud deposit had a radiocarbon age of 1,610±200 years.

much as 1 m thick. The sand decreases in thickness and generally disappears within a kilometer of the canyons. The sand deposits probably originated when avalanches of loose material fell from the canyon walls and produced local clouds of fine-grained material. Winds then carried the sand short distances from the canyon.

## Age and Origin of the Timberline Deposits

BECAUSE their distribution is limited to the south and southwest flanks of Mount Hood, the mudflows and pyroclastic-flow deposits of Timberline age are believed to have resulted from an eruption at the present south-facing crater of the volcano. The nonvesicular nature of the rock debris in these deposits suggests that the material was derived from a dacite dome that was being extruded within the crater; as the flanks of the dome collapsed, some of the hot rock debris rushed downslope as pyroclastic flows. Melting of snow by the hot debris produced water that remobilized both hot and cold rock material as mudflows that moved into the river valleys draining the south and west sides of the volcano. Some mudflows probably were also caused by runoff during rainstorms. Clouds of ash generated by pyroclastic flows were carried away by winds and were deposited on all flanks of the volcano, but principally on the south, east, and northeast sides. Pumice was erupted some time during the Timberline period, but the quantity was so small that only scattered lapilli can now be found on the east and northeast sides of Mount Hood.

Radiocarbon dates on samples of Timberline age range from 1,530±200 to 1,780±200 years. However, because of the range of possible error indicated in these dates, the exact duration of the eruptive period is not known. At one locality some evidence suggests that a brief dormant interval occurred during the Timberline period. At the top of the White River canyon east of Timberline Lodge, two deposits of reddish-gray ash are separated by brown windblown sand and a thin layer of forest litter. If both deposits of ash are of Timberline age, as is suggested by their color, their formation evidently was separated by an interval of a few decades or perhaps as much as a century.

# Old Maid Eruptive Period

ROCKS and unconsolidated deposits of Old Maid age include a dacite dome in Mount Hood's crater, a pyroclastic flow, and many mudflows in the White and Sandy River valleys. These products of volcanism probably are all between 200 and 300 years old, and represent Mount Hood's last major eruptive period.

## Deposits in the Sandy River Valley

DEPOSITS of Old Maid age in the Sandy River valley consist of coarse mudflows that underlie the valley floor and adjacent terraces between the Upper Sandy Guard Station and the community of Zigzag; these deposits form Old Maid Flat. Old Maid Flat is underlain by a succession of mudflow deposits, each generally less than 2 m thick, rather than by a single very large mudflow. Rocks in these mudflows typically are light-gray hypersthene-hornblende dacite, some of which contains rare augite. Blocks of this rock are abundant on the surface of the mudflow deposits and are as much as several meters in diameter on the upvalley portion of Old Maid Flat.

Old Maid deposits form terraces at several heights in the Sandy River valley near the Upper Sandy Guard Station. The highest and widest terrace is about 45 m above the Sandy River flood plain and about 15 m lower than a terrace on the south side of the valley that is underlain by mudflows of Timberline age. Three lower terraces in this part of the valley, at heights of 3.5, 7.5, and 18 m above the flood plain, also are underlain by mudflows of Old Maid age. These surfaces evidently were formed during times of mudflow deposition that were separated by longer periods of downcutting by the Sandy River.

Large stumps of trees that were buried by mudflows of Old Maid age indicate that a mature forest was growing on the valley floor at the beginning of the Old Maid eruptive period. Upstream from the Upper Sandy Guard Station, buried tree stumps near the base of the Old Maid deposits are rooted in underlying mudflows of Timberline age. Downstream, at a site just south of Muddy Fork (near the junction of Portage and Timberline Trails), partly buried stumps project from mudflow deposits of Old Maid age. Some have toppled and lie rotting on the ground. Other buried trees have rotted away entirely and have left large vertical "tree wells" that are open at the ground surface. Buried stumps can also be seen in the banks of Muddy Fork at least as far downstream as the junction of the Lolo Pass and Muddy Fork Roads and adjacent to Lost Creek along the south side of Old Maid Flat. Wood samples from two stumps at the margins of Old Maid Flat yielded radiocarbon ages of less than 250 years; according to Rubin and Alexander (1960), the wood may be about 200 years old. Growth-ring counts of the stumps of trees that grew on top of the mudflows indicated an age of at least 176 years (Rubin and Alexander, 1960, p. 161).

One of the most interesting deposits of Old Maid age in the Sandy River valley is a mudflow that carried some hot rock fragments (fig. 12). This deposit crops out in the north bank of the Sandy River at a point about 0.3 km southeast (upvalley) of the junction of the Portage and Sandy River Trails. At this locality, the mudflow is 0.5–1 m thick and contains blocks of dacite as much as 50 cm in diameter in a matrix of fine to coarse sand. Eight rock fragments 10–20 cm in diameter from this deposit were examined with a portable magnetometer. Four of these fragments, each of nonvesicular dacite, had random directions of remanent magnetism, which suggests that they were not at a high temperature when the mudflow came to rest. Three samples of slightly vesicular dacite, each of which were taken from prismatically jointed blocks, as well as one sample of nonvesicular dacite, all had directions of remanent magnetism that coincide with the Earth's present magnetic field; thus, these blocks probably were at temperatures of at least several hundred degrees Celsius when the mudflow came to rest.

The mudflow also contains abundant wood fragments that are partly or wholly charred, as well as many that are uncharred. Selective charring like this probably can be attributed to the proximity of wood to hot rock fragments during movement of the mudflow or after it came to rest. Despite this evidence of heat, the presence of uncharred wood suggests

FIGURE 12.—Mudflow of Old Maid age (above dashed line) overlying mudflows of Timberline age in north bank of the Sandy River 0.3 km southeast of the junction of the Portage and Sandy River Trails. The Old Maid mudflow is about 1 m thick.

that the deposit was formed by a hot mudflow rather than a pyroclastic flow. In the deposit of a hot pyroclastic flow, all wood fragments are completely charred.

Charred wood from the mudflow has a radiocarbon age of 220±150 years (table 1). Correction of this date by known variations in atmospheric radiocarbon (Stuiver, 1978) indicates that the mudflow probably occurred between A.D. 1660 and 1790.

The hot mudflow probably occurred during an early part of the Old Maid eruptive period; it was followed by erosion by the Sandy River, then by deposition of the voluminous mudflows that form Old Maid Flat.

## Deposits in the White River Valley

DEPOSITS of Old Maid age in the White River valley include two groups of units of slightly different age: an older group of pyroclastic-flow deposits and mudflows, and a younger group of mudflows. The older deposits crop out in the face of a terrace along the west side of White River upstream from State Highway 35 (fig. 13). They include a basal deposit more than 3 m thick that contains dacite fragments mostly less than 0.5 m in diameter in a loose matrix of fine to very fine gray sand. The presence of both charred and uncharred wood in this deposit suggests that it was formed by a mudflow carrying some hot rock fragments. The deposit extends below the level of the White River and is overlain by a pyroclastic-flow deposit 5–20 m thick (fig. 14). The pyroclastic-flow deposit consists of a mixture of dacite fragments as much as 1.5 m in diameter in a semicompact matrix of gray, reddish-gray, and grayish-brown sand. Blocks of dacite as much as 6 m in diameter, many of which are prismatically jointed, litter the terrace. Examination of samples of several jointed blocks using a portable magnetometer gave directions of remanent magnetism that coincide with the Earth's present magnetic field; thus, these blocks probably were at a temperature of at least several hundred degrees Celsius when they came to rest. A chemical analysis of one such block is given in appendix C.

The pyroclastic-flow deposit contains abundant fragments of wood, all of which are charred. A sample of one of these fragments yielded a radiocarbon age of $260 \pm 150$ years (table 1). Correction of this date by known variations in atmospheric radiocarbon (Stuiver, 1978) suggests that the pyroclastic flow occurred about A.D. 1640.

At its top, this deposit has a reddish-gray to yellowish-brown zone, 0.5–1.5 m thick, in which many stones are coated with yellowish-brown to reddish-brown iron oxides (fig. 15). The coatings are most common and conspicuous on the lower sides of stones. In addition, small areas of the matrix in this zone are also permeated with yellowish-brown coatings on sand grains. This discoloration at the top of the deposit is not part of a soil profile because deposits this young typically are virtually devoid of soil oxidation. Thus, both the reddish-gray

FIGURE 13.—Terrace along the west side of the White River about 1 km upstream from State Highway 35. The conspicuous planar textural break in the Old Maid deposits that form the terrace is at the contact between a mudflow (below) and a pyroclastic-flow deposit. (See fig. 14.) The terrace is at a height of about 25 m above the White River flood plain in the foreground.

FIGURE 15.—Zone of reddish-gray to yellowish-brown oxidation at the top of the pyroclastic-flow deposit of Old Maid age in the White River valley about 0.7 km north of State Highway 35. This zone, as well as the yellowish-brown to reddish-brown iron oxides that coat many of these stones, evidently was discolored by iron-bearing gases after the pyroclastic flow came to rest.

zone and the coatings are inferred to have resulted from deposition of iron-bearing material that was being carried upward by hot gases after the pyroclastic flow came to rest and as it cooled.

The pyroclastic flow that forms the terrace is locally overlain by four lenticular mudflows that thin and disappear from the terrace in a downstream direction. The individual mudflows are each as much as 1.5 m thick; they are interbedded with sand a few centimeters to several tens of centimeters thick. Some of the mudflows contain prismatically jointed blocks of dacite.

---

◁ FIGURE 14.—Pyroclastic-flow deposit of Old Maid age (foreground) forms a terrace that is about 25 m above the White River. (See fig. 13.) A lower terrace in the right center of the photograph is underlain by slightly younger mudflows. (See fig. 16.)

The gradient of the terrace formed by the Old Maid deposits steepens downvalley at a point about 0.4 km from State Highway 35 (about 7.5 km from Mount Hood's crater), and the terrace merges with the White River flood plain between that point and the highway.

Near the point at which it begins to steepen downstream, the Old Maid terrace is about 25 m above the White River. The terrace does not slope as steeply as does the adjacent flood plain; consequently, the height of the terrace decreases upstream and is only a few meters above the White River at the upstream point where the terrace disappears. The pyroclastic-flow deposit was not recognized in the valley farther upstream. It is possible that the pyroclastic flow did not leave thick deposits in the upper part of the valley because the steeper slopes there gave it greater mobility.

The younger part of the Old Maid deposits in the White River valley consists of a succession of bouldery mudflows. these formed a valley fill, now trenched by the White River, whose surface is about 100 m above the river east of Timberline Lodge (fig. 16). The fill surface slopes more steeply than does the White River and merges downvalley with the flood plain at a point about 1.5 km from State Highway 35. A fan of mudflows and river deposits downstream from the highway probably is in part the downvalley correlative of the mudflow fill.

No prismatically jointed blocks of dacite were seen in the young succession of bouldery mudflows, no reddish-gray zones were noted at the top of any of the individual deposits, and upright tree stumps buried at the base of the deposits are not charred; thus, these mudflows evidently were carrying only cold rock debris. The radiocarbon age of a sample of one of the stumps at the base of the mudflows was 250±150 years (table 1).

Topographic relations between the older and younger Old Maid terrace deposits in the White River valley indicate that, after the older deposits were formed, the White River cut down at least as far as the level of the present flood plain. The resulting valley subsequently was partly filled by the mudflows that underlie the younger, lower terrace. The close

FIGURE 16.—View south-southeastward down the White River canyon of a fill terrace formed by mudflows of Old Maid age. Note stumps (indicated by arrows) at base of the fill deposits; one of these had a radiocarbon age of $250 \pm 150$ years. At this locality, the terrace is about 60 m above the bottom of the gully to the right.

correspondence between the radiocarbon dates on the two groups of deposits suggests, however, that an appreciable amount of time did not elapse between formation of the two parts of the Old Maid deposits.

## Crater Rock Dome

MOUNT Hood's crater contains a dome of hypersthene-hornblende dacite called Crater Rock. The dome is about 300–400 m across its base and about 170 m high on its south side (fig. 17). According to Wise (1969), the solid rock of the dome is surrounded by a zone of brecciated rock of the same composition. A chemical analysis of the dome rock is given in appendix C.

FIGURE 17.—Crater Rock (arrow), in the center of Mount Hood's crater, is a remnant of a dacite dome that was erupted between 200 and 300 years ago. The top of Crater Rock rises about 170 m above its base.

Crater Rock is believed to be a remnant of a dacite dome that was formed 200–300 years ago. This age assignment is based on the ages of the pyroclastic-flow deposits and mudflows in the White and Sandy River valleys described above, which are inferred to have been formed as the dome was being extruded. No large-volume source of dacitic rock debris other than the dome exists at the heads of these two valleys. Such a relatively young age assignment is consistent with the extensive fumarolic activity that persists today at and adjacent to Crater Rock. Although Wise (1966, 1969) believed Crater Rock to be the source of the broad fan of rock debris on the south side of the volcano (Timberline deposits of this report), that debris evidently originated at another dacite dome at the same location.

The masses of Old Maid rock debris in the Sandy and White River valleys that were derived from the dome greatly exceed Crater Rock in volume. If it is assumed that the deposits of Old Maid age in the Sandy River valley upstream from Zigzag have an average thickness of 10 m, their total volume is a little more than 100 million $m^3$. A similar volume can be calculated for similar deposits in the White River valley if it is assumed that they have an average thickness of 25 m, which is the maximum height of the terrace formed by pyroclastic-flow and mudflow deposits. If the volume of all these deposits is arbitrarily reduced by 30 percent to allow for the greater porosity of these deposits than of solid rock and for possible inclusion of material that was not derived from the dome, the resulting volume of the rock mass from which these deposits were derived is about 140 million $m^3$, which is about 20 times the estimated volume of 7 million $m^3$ of Crater Rock. A cylinder of rock with a diameter equal to that of the base of Crater Rock and a volume of 140 million $m^3$ would have a height of a little more than 1,000 m. However, as the dome was extruded, it probably was never significantly larger and higher than it is today, because rockfalls and avalanches probably lowered it as quickly as it was formed.

## Ash-Cloud(?) Deposit

A deposit of light-gray lithic ash mantles much of the lower slopes of Mount Hood. At most places the ash directly underlies the ground surface and is covered only by recent forest litter. The ash consists chiefly of fine particles of rock, feldspar, and other mineral fragments; ferromagnesian minerals in the ash include hypersthene, hornblende, and augite in variable proportions. Pumice was not observed in the ash. Most of the ash ranges in size from silt to medium sand, although at some localities there are scattered rock fragments as much as 5 mm in diameter. The maximum observed thickness (about 17 cm) was seen in a roadcut about 150 m north of Tilly Jane Guard Station on the northeast side of the volcano, and a thickness of 14 cm was noted on Yokum Ridge 4 km west of the summit of Mount Hood. The ash is as much as 10 cm thick on the lower slopes of Cooper Spur and near the mouth of the Polallie Creek. Elsewhere, the ash seems to range from less than 1 cm to about 7 cm. A thickness of about 1 cm was observed in a trail cut on Bald Mountain a little more than 7 km west-northwest of the summit of the volcano.

This ash evidently is the same layer as that described by Lawrence (1948), who reported thicknesses of as much as about 15 cm and, on the basis of observations at about 30 localities, drew tentative lines of equal thickness around the volcano (fig. 18). With few exceptions, the thicknesses that I observed generally agree with those of Lawrence. The distribution of the ash on all sides of the volcano suggests that it was transported and deposited by winds blowing in various directions during an extended period of time.

Lawrence believed that the ash was deposited between 1760 and 1810 and most probably about 1800. This age estimate was based on the presence of the ash on a lateral moraine believed by Lawrence to have been formed about A.D. 1740; the lack of a soil between the ash and the underlying moraine was interpreted by him as evidence that the ash is not much younger than the moraine. However, he presented no conclusive evidence that the ash was deposited as recently as 1800.

Lawrence suggested that the ash was erupted at a vent in Mount Hood's crater in the vicinity of Crater Rock. If so, the ash could have originated in repeated steam explosions like those at Mount St. Helens in late March and early April, 1980. Variable winds during that period carried small amounts of ash away from the volcano in nearly every direc-

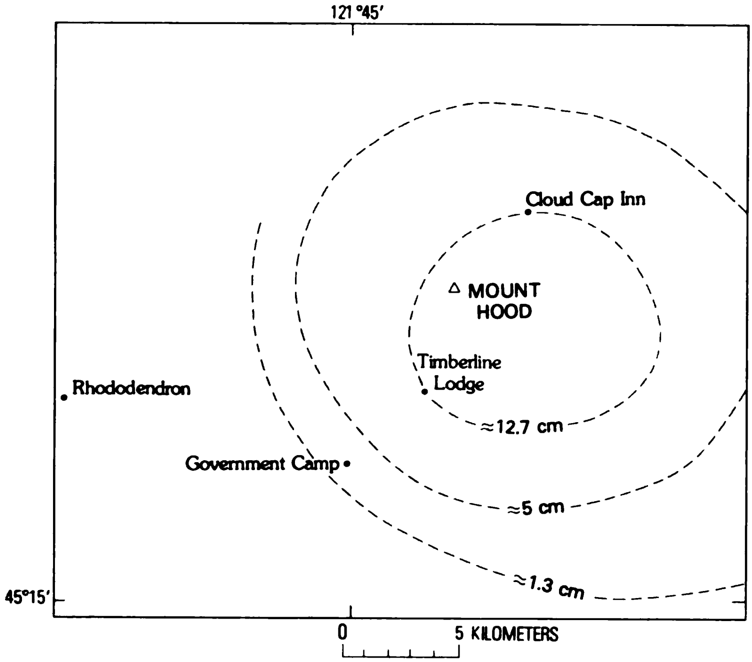



FIGURE 18.—Map showing approximate isopachs (lines of equal thickness) of ash-cloud(?) deposit of Old Maid age (from Lawrence, 1948, fig. 2).

tion. This ash was not derived from new molten rock, but resulted from the explosive disruption of older rocks within the volcano.

It is also possible that the deposit was formed during the extrusion of the Crater Rock dome and that it represents fine-grained airborne dust that was produced by rockfalls and avalanches of debris from the flanks of the dome as it was being extruded.

## Recent Flood Deposits

A very coarse, gray, and unweathered deposit of sand and boulder gravel forms a fan in the East Fork Hood River valley at the mouth of Polallie Creek and is preserved farther downstream in a terrace that is between 5 and 10 m above river level. Abundant blocks of gray andesite as large as 5 m in diameter are scattered on the surface of the fan and terrace.

The oldest tree found on the fan is represented by a recently cut stump that has 150 annual growth rings at a height of 40 cm above the ground surface. The light-gray ash described previously could not be found on the fan, and it is concluded that the flood deposit was formed some time during the early 1800's.

At Tucker Park, 32 km downstream from the mouth of Polallie Creek and 6 km southwest of the community of Hood River, similar unweathered bouldery deposits form terraces at heights of about 5, 7, and 9 m above the Hood River. Although the deposits were not traced from Polallie Creek to Tucker Park, it seems likely that they are correlative. The deposits at Tucker Park contain abundant boulders 1-2 m in diameter, and the 7-m terrace has a block of andesite that is nearly 6 m in diameter. A core taken at a height of 60 cm from one of the largest trees growing on the 5-m terrace had 100 annual growth rings.

Although these coarse deposits must have resulted from some kind of unusual event in the Polallie Creek valley, no evidence was found that they were caused by volcanism. Polallie Creek heads in coarse pyroclastic-flow and mudflow deposits of Polallie age and is flanked by these deposits throughout its course. The bouldery deposits downstream from Polallie Creek evidently resulted from exceptionally high discharge in the Polallie Creek valley, which undercut unconsolidated deposits in its banks, and this high discharge probably was caused by unusually heavy precipitation.

## Recent (Historic?) Pumice

SCATTERED lapilli of gray pumice are present at the ground surface on the south, east, and northeast sides of Mount Hood, but nowhere do the lapilli form a continuous layer. The largest fragment noted on the ridge 1.3 km west of Mount Hood Meadows was $1.9 \times 2.5 \times 2.3$ cm in dimension, and one on a ridge 1.5 km north-northeast of Mount Hood Meadows was $3 \times 4 \times 5.5$ cm. The lapilli are generally less than a centimeter in diameter in the areas west of Timberline Lodge, along the East Fork Hood River valley, and near Cloud Cap Inn. Ferromagnesian minerals in the pumice are hypersthene and hornblende; augite is very rare. The chemical composition of a sample of the pumice is given in appendix C.

The recent pumice can be found on top of the pyroclastic flow of Old Maid age in the White River valley; thus, the pumice probably is less than 200 years old. The pumice may have been erupted during the middle of the 19th century.

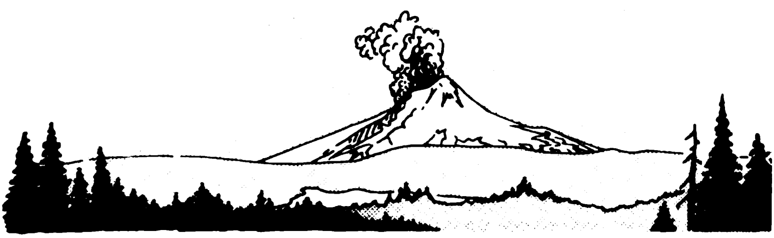
A minor eruption of Mount Hood in September 1859 was witnessed by W. F. Courtney (letter to Everett, Wash., Record, May 1902, quoted in Harris, 1976, p. 147), who reported the following:

> We were camped on Tie Ridge about thirty-five miles from Mt. Hood. It was about 1:30 o'clock in the morning * * * when suddenly the heavens lit up and from the dark there shot up a column of fire. With a flash that illuminated the whole mountainside with a pinkish glare, the flame danced from the crater * * * For two hours, as we watched, the mountain continued to blaze at irregular intervals, and when morning came Mt. Hood presented a peculiar sight. His sides, where the day before there was snow, were blackened as if cinders and ashes had been thrown out.

An event that probably was another minor eruption of Mount Hood was witnessed in 1865 by John Dever, a soldier stationed at Fort Vancouver, Wash., 80 km west-northwest of the volcano. He reported (letter to Portland Oregonian, September 26, 1865) that he saw between 5 and 7 a.m. on September 21,

> * * * the top of Mount Hood enveloped in smoke and flame * * * real jets of flame shot upwards seemingly a distance of fifteen or twenty feet above the mountain's height, accompanied by discharges of what appeared to be fragments of rock, which I could perceive fell immediately after with a rumbling noise not unlike distant thunder.

Although the recent pumice that is scattered on the slopes of Mount Hood could have been erupted either in 1859 or 1865, it also could be the product of more than one eruption.



Mount Hood as seen from the northeast.

# PART II
# VOLCANIC HAZARDS ASSESSMENT

## Potential Volcanic Hazards

POTENTIALLY HAZARDOUS PHENOMENA that could result from an eruption at Mount Hood include pyroclastic flows, lateral blasts caused by volcanic explosions, mudflows, and floods. In addition, a small amount of tephra could fall on the flanks of the volcano and adjacent areas.

Lava flows evidently have not been erupted at Mount Hood volcano during the time since the last glaciation, and there is no reason to believe that flows will be erupted in the foreseeable future. If a lava flow were to be erupted, however, its source vent could be located anywhere on Mount Hood, or even beyond the base of the volcano, as is the source vent for the lava flow west of Parkdale. Fortunately, lava flows that have chemical compositions like those of rocks erupted at Mount Hood during the last 15,000 years do not constitute a major risk to lives because such flows are highly viscuous and typically move very slowly. Furthermore, when a lava flow is erupted, the general area of potential hazard will be known immediately because lava moves away from its source in a downslope direction, and its extent will thus be determined by the topography and by the volume of lava that is erupted.

Possible dangers that could be associated with eruptive phenomena other than lava flows at Mount Hood are described in the following section.

### Pyroclastic Flows and Associated Ash Clouds

THE repeated formation of domes during several geologically recent eruptive periods at Mount Hood and the relative rarity of other types of volcanic activity indicate that the type of eruption most likely in the future will be the eruption of another dacite dome, probably at or near Crater Rock. Such an eruption almost certainly will produce avalanches of hot rock debris which, if large enough, will move far down the flank of the volcano as pyroclastic flows. Such flows are especially dangerous because they travel at high speed and tend to bury and incinerate everything in their paths. Because of the relatively steep slopes on Mount Hood pyroclastic flows probably will move at speeds of 50 to more than 150 km/h.

If a large volume (0.1 $km^3$ or more) of lava is erupted in the form of a dome, pyroclastic flows and mudflows from the dome will tend to fill topographically low areas and may form deposits tens of meters thick in the valleys they follow. This is the behavior shown by pyroclastic flows and mudflows of previous eruptive periods. By analogy with domes that have been formed elsewhere during historic time, it should be assumed that the extrusion of a dome will continue for an extended period of time, perhaps many months or even several years, and it should be assumed that pyroclastic flows could occur at any time during dome formation.

Clouds of ash that are generated by pyroclastic flows can form extensive deposits downwind from flows. Although the deposit associated with any one pyroclastic flow may be no more than a few centimeters thick, recurring flows may result in much thicker accumulations, especially in the direction of the prevailing winds. The area covered by an ash-cloud deposit will be determined by the length of the pyroclastic flow, the height of the ash cloud above the flow, and the direction and strength of winds.

Ash clouds constitute a hazard to human life because of their possible high temperature, especially within a few kilometers downwind from the pyroclastic flow. Such clouds may cause asphyxiation and burning of the lungs and skin, as well as abrasion of objects in their paths. The resulting deposits will blanket and perhaps kill vegetation and may block highways. Other potential hazards are similar to those of tephra, discussed subsequently.

## Explosive Lateral Blasts

THE formation of domes commonly is accompanied by volcanic explosions that can throw rock debris laterally outward at high speeds to distances of many kilometers. Such a lateral blast during the eruption of a dacite dome at Mount St. Helens about 1,100 years ago carried hot fragments of the dome outward to a distance of at least 10 km (D. R. Mullineaux, oral commun., 1978). A similar explosion occurred during the eruption of a highly viscous lava flow at the summit crater of Lassen Peak in 1915. The resulting hot blast destroyed a mature forest at the north base of the volcano to a distance of about 5 km, and individual rock fragments were carried even farther.

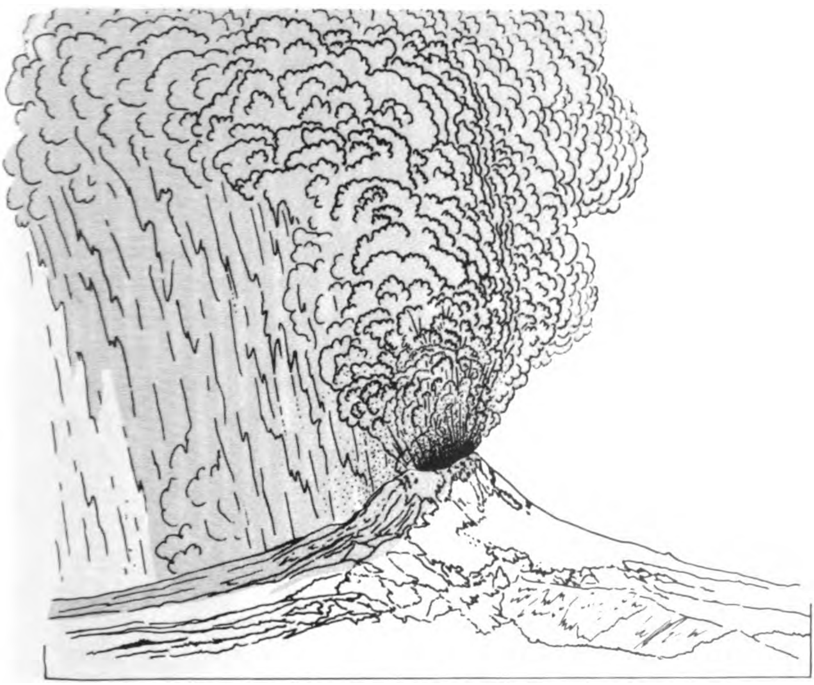
The principal dangers from lateral blasts are from airblast and the impact of rock fragments moving at high speed.

## Tephra

TEPHRA usually is projected high above a volcano by the force of the eruption and by hot ascending gases. Typically, winds then carry the material away from the volcano, and it falls to the ground at a distance determined by the height to which the tephra was erupted, by the size of the fragments, and by wind directions and speeds. Large blocks fall close to the vent or may be thrown, like projectiles, onto the flanks of the volcano. If a large volume of tephra is erupted, a continuous layer will accumulate in the fallout area. At Mount Hood, however, eruptions of pumiceous tephra during the last 15,000 years have been of such small volume that only scattered fragments can now be found, rather than continuous layers.

Although the likelihood of a voluminous tephra eruption in the near future seems very low at Mount Hood, the effects of such an eruption could be very serious. Falling tephra can endanger lives and property by the force of the impact, by forming a blanket covering the ground, by producing a suspension of fine particles in air and water, by carrying acids, and, close to the vent, by heat. People can be injured by breathing tephra-contaminated air, by the collapse of tephra-laden roofs, and by fires started by the hot fragments. Tephra can block roads if it is thick enough, can cause darkness, can increase acidity in exposed water supplies, and can interrupt telephone, radio, and electrical services. Damage to property can result from the weight of tephra, from its smothering effect, from abrasion, and from corrosion. Machinery is especially susceptible to damage from abrasion and corrosion both during the initial fall of the material and later, while the material is still loose enough to be redistributed by wind.

The probable extent of future tephra falls at Mount Hood, like those of the geologically recent past, will be within the hazard zones shown on plate 1 for ash clouds and lateral blasts.



Mount Hood as seen from the east.

# Mudflows and Floods

AMONG the many ways mudflows can originate (Crandell, 1971, p. 8–10), the most likely origin at Mount Hood is a pyroclastic flow moving across snow. The rock debris in mudflows can be hot or cold or both. Mudflows can travel distances of many tens of kilometers, and their velocities depend chiefly on volume, fluidity, and the gradient of the surface over which they move. Speeds of as much as 180 km/h have been reported on very steep slopes, and speeds of 20–40 km/h can be expected even on gently sloping valley floors. Mudflows tend to move along stream channels, but those of large volume may overtop streambanks and spread across entire valley floors.

The chief dangers to human life are those due to burial and to the impact of boulders carried in mudflows. In addition, mudflows carrying hot rock debris can cause scalds or severe burns. Buildings can be buried, smashed, or moved. Because of their high viscosities, mudflows can sweep away bridges and other massive structures in their paths. Natural and artificial constrictions that impede flowage in a valley, such as narrow gorges and road embankments, cause mudflows to pond and to attain thicknesses (depths) far greater than those in areas where they can spread freely.

The dangers presented by floods caused by volcanism are similar to those in floods having other causes. Floods can wash out bridges and erode unprotected natural and artificial embankments, thereby causing structures adjacent to river channels to collapse. Floods related to volcanism probably will carry unusually large amounts of rock debris, and deposits of sand and gravel many meters thick may accumulate on valley floors where the carrying power of the water decreases for any reason. If pyroclastic flows were to melt snow on the volcano during a time of flooding, unusually high discharge rates could be expected in streams and rivers.

## Volcanic Gases

VOLCANOES emit variable amounts of gases during eruptions. These gases consist chiefly of water vapor, carbon dioxide, carbon monoxide, and compounds of sulfur, chlorine, and nitrogen. Quiet emission may result in gas concentrations near a vent, especially in topographic depressions, but gas generally is diluted and dispersed rapidly by wind. Gases erupted under great pressure may be driven laterally away from a vent at high speed, but they quickly lose speed and then disperse. Dilute gas odors have been reported many tens of kilometers downwind from volcanoes.

Some volcanic gases can be dangerous to health or life as well as to property (Wilcox, 1959, p. 442–444). Gases are potentially injurious to people, mainly because of the effects of acid and ammonia compounds on eyes and lungs, and enough carbon dioxide and carbon monoxide can collect in basins to cause suffocation. Certain gases can harm plants and can poison animals that eat the plants. The cumulative effect of dilute volcanic gases over a long period may cause substantial property damage at distance of many tens of kilometers downwind from a volcano.

No historic basis exists for predicting the specific extent of potential gas-hazard zones at Mount Hood in the event of an eruption; however, the effects of gases can generally be assumed to be greatest close to the volcano and immediately downwind from the active vent.

# Hazard Zones

AREAS OF POTENTIAL HAZARD around Mount Hood are subdivided into four main groups according to whether the hazard is the result of pyroclastic flows, lateral blasts, ash clouds, or mudflows and floods. Each of these groups, except that related to ash clouds, is subdivided according to whether the eruption will occur at the present crater or at some other location high on the volcano. In addition, the mudflow and flood hazard zone related to an eruption at the present crater is further subdivided into areas of initial and immediate danger, and additional areas that will be affected if the eruption continues and involves a large volume of material. Each of these subdivisions is discussed in the following paragraphs and is shown on plate 1.

## Pyroclastic-Flow, Mudflow, and Flood Hazard Zones PA and PB

THE extent of zone PA is based on the assumption that a dome will be erupted within the present crater of Mount Hood at the site of, or adjacent to, Crater Rock. The zone is limited to areas that are downslope and downvalley from the crater to a distance of 8 km, which is the approximate length of a pyroclastic flow of Old Maid age in the White River valley. The extent of zone PB is based on the assumption that a dome will be formed at some point on the volcano above about 2,750 m (9,000 ft), but not within or downslope from the present crater. The zone includes areas downslope and downvalley to a distance of 8 km from the 9,000-ft contour.

Although zones PA and PB include hazards from mudflows and floods, the extents of the zones are based chiefly on the anticipated behavior of future pyroclastic flows because they are regarded as potentially the most dangerous type of hazard. The lateral boundaries of the zones are based on the assumption that a pyroclastic flow will locally rise as much as a few tens of meters on the sides of the valley it descends and to greater heights in areas where the valley is constricted. The areas adjacent to the basal part of the pyroclastic flow can be affected by clouds of initially hot ash whose effects will rapidly diminish in a downwind direction. Boundaries between pyroclastic-flow hazard zones and adjacent ash-cloud hazard zones are transitional over perhaps as much as 1 km.

## Mudflow and Flood Hazard Zones MA, MB, and M

THE area included in zone MA consists of part of the lower south flank of the volcano and the channels of streams and rivers that head on the part of the volcano that is downslope from the present crater. These channels probably will be the first areas to be affected by mudflows and floods resulting from an eruption in the present crater; consequently, the channels are more hazardous that are adjacent, higher areas of valley floors. Zone MB includes the floors of valleys that head on the part of the volcano that is downslope from the present crater; it also includes surfaces that are 5–15 m above present rivers. These areas may not be affected initially by floods and mudflows caused by future eruptions, but they could be endangered if an eruption continues and causes deposits of floods and mudflows to fill existing river channels. Zone M includes the floors of valleys downslope from parts of the volcano that do not head within the present crater.

The lateral boundaries of zones MA and M are based partly on contours shown on the topographic map and partly on an inspection of aerial photographs which show areas of recent flood devastation along valley floors. Lateral boundaries of zone MB are based on the topography of valley floors as indicated by contours. Because the sizes of future mudflows and floods can not be predicted, the boundaries are approximations and, in places, may be accurate only to within a few hundred meters.

Highways and bridges that are located in mudflow and flood hazard zones MA and M are especially susceptible to damage or destruction not only by phenomena associated with eruptions but also by floods caused by weather conditions.

Such floods can erode the banks of rivers and undermine adjacent houses and other structures, as in December 1964, when the Zigzag River washed out bridges or their abutments along U.S. Highway 26 and temporarily isolated the community of Rhododendron. On December 29, 1964, the Portland Oregonian carried the news that:

> The Zigzag, in many places hundreds of feet from its former bed is lined with houses hanging crazily over the undercut banks. Many of the stream-side homes are entirely gone—no one yet knows how many—along with the soil on which they were built.

Areas that are susceptible to the effects of flooding along the branches of the Hood River are identified on a geologic-hazards map of the Hood River quadrangle and are discussed in an accompanying report (Beaulieu, 1977).

## Lateral-Blast Hazard Zones LA and LB

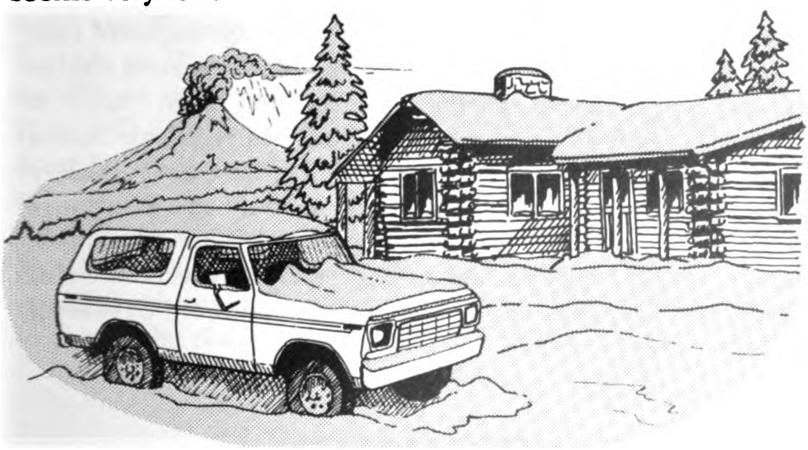
HAZARD zones LA and LB are subject to the effects of lateral blasts caused by volcanic explosions during an eruption. The extent of zone LA is based on the assumption that an explosion may occur during the extrusion of a dome within the present crater, and the extent of zone LB is based on the assumption that an explosion may occur during the formation of a dome elsewhere high on the volcano. The outer limits of the zones, about 10 km from the summit of the volcano, are based on the distance rock fragments were thrown by an explosion during the eruption of a dome at Mount St. Helens about 1,100 years ago. The risk to life and property from rock debris thrown outward by a lateral blast decreases progressively with distance from the summit of the volcano.

## Ash-Cloud Hazard Zone

THE ash-cloud hazard zone includes areas that could be covered by 20 cm or more of ash generated by pyroclastic flows. The distribution and thickness of ash probably will be determined by the location, number, and size of pyroclastic flows, and by the direction and speed of winds that carry the ash away as the pyroclastic flows move downslope. This zone could also be affected by ash and lapilli erupted directly from a vent high on the volcano, but if future eruptions are like those of the recent past, the resulting deposits will not form a continuous layer of appreciable thickness.

The extent of the ash-cloud hazard zone is based on the distribution and thickness of ash-cloud deposits of Timberline age relative to the probable sources of those deposits. In determining the limit of the zone (pl. 1), it was assumed that ash-cloud deposits at least 20 cm thick can accumulate at a maximum distance of 11 km from hazard zones PA and PB. The limited westward extent of the ash-cloud hazard zone is based on the assumption that winds will be blowing to the east in a sector defined by 22½° east of north and 22½° east of south.

In the discussion of the Parkdale soils (p. 25), it is suggested that the deposit was formed by ash clouds carried by winds northward from pyroclastic flows descending the northeast slopes of the volcano. If this is true, what is the chance that ash-cloud deposits as much as 4 m thick will accumulate in the Upper Hood River Valley as the result of future volcanic activity? The distribution of ash-cloud deposits probably is controlled by winds at altitudes lower, rather than higher, than the top of the volcano. At Salem, Oreg., the nearest point at which wind records are available, only 5 percent of winds at an altitude of about 2,500 m are from the south. (See fig. 20.) Thus, if it can be assumed that wind directions in the Mount Hood region are similar to those at Salem, the risk of thick ash accumulating in the Upper Hood River Valley in the future seems very low.



## Discussion of Hazard Zones

THE hazard-zone boundaries shown on plate 1 can be used only in a very general way to anticipate the extent of a potential hazard. For example, the actual volume of a future pyroclastic flow or mudflow cannot be predicted; thus, its width, depth, and length will not be known until after it occurs. Moreover, possible inaccuracies in the location of the zone boundaries shown on plate 1, small inaccuracies in the base map, and changes in river courses and the location of highways and other manmade features since the base maps were made all combine to make the map useful only as a rough guide to possible hazard areas. Furthermore, an inverse relation exists between the size of mudflows and their frequency—mudflows of small volume are far more common than very large ones. Thus, the risk from mudflows at any one place within a valley decreases progressively with increasing height above a river and generally becomes negligible above a height of several tens of meters (fig. 19). For the same reason, the risk from mudflows also becomes progressively less in a downstream direction, but this decrease occurs over a distance of several tens of kilometers. The same relations are generally true for pyroclastic flows that move down valley floors, although the ash clouds that accompany them can affect adjacent valley walls to heights of hundreds of meters. The boundaries shown for the lengths of future pyroclastic flows are based on an actual event, but many future flows probably will be shorter, and some will be longer.

It cannot be emphasized too strongly that the degree of risk from volcanic phenomena is gradational: the greatest risk is on the upper slopes of the volcano, and from there it diminishes with distance and, in the case of pyroclastic flows, mudflows, and floods, with increasing height above valley floors. Lines that delineate zones of potential hazard on plate 1 are based on the assumption that future eruptive events will be similar to those of the last 15,000 years; however, there can be no assurance that areas beyond those lines are devoid of risk.

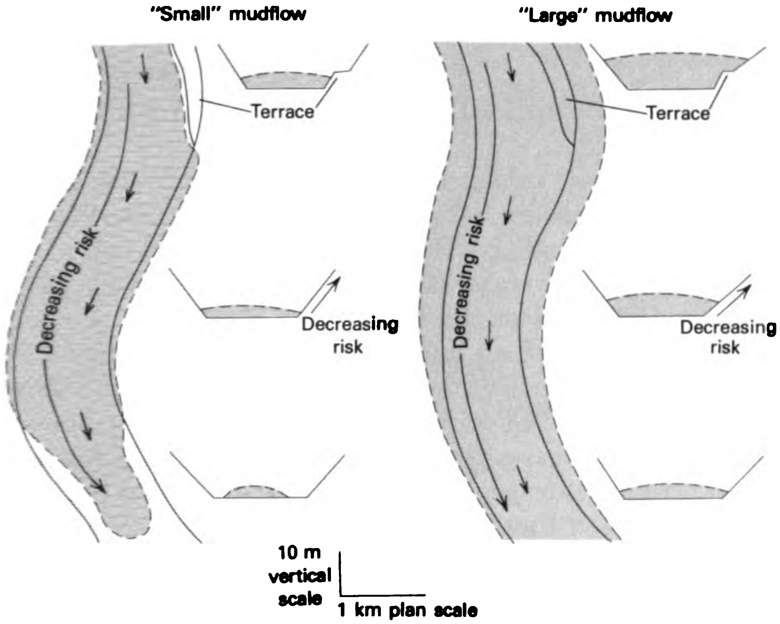



FIGURE 19.—Diagrammatic maps and cross sections of hypothetical mudflows, showing relations of potential risk to length and thickness (depth) in a valley, "Small" mudflows occur more frequently than "large" mudflows. The shaded portions show extent and maximum height reached by mudflows, but thicknesses that remain after mudflows come to rest may be substantially less. Short arrows point downvalley.

The character of recent eruptive activity suggests that there is little or no danger that the next eruption of Mount Hood will significantly affect the Portland metropolitan area. Future mudflows that reach the Columbia River will probably be of such small volume at that distance from the volcano that they will have virtually no effect on the discharge of the Columbia. Inasmuch as no appreciable volume of pumiceous tephra has been erupted at Mount Hood during the last 15,000 years, the probability that large-volume eruptions of this kind will occur in the near future seems to be exceedingly small. In the unlikely event that a large volume of tephra were erupted, the chance is small that a significant amount would

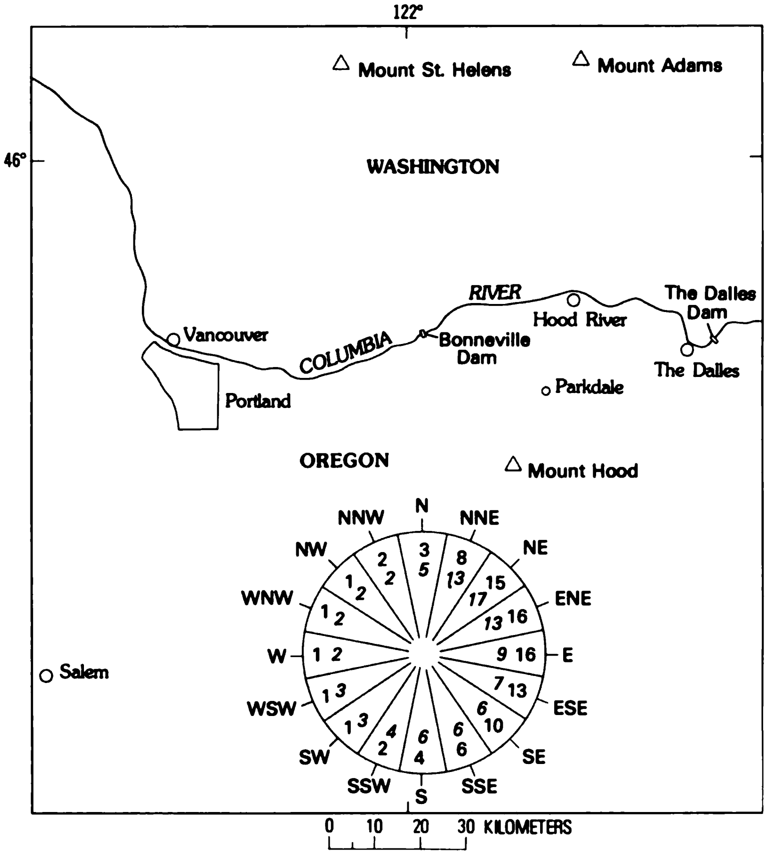



FIGURE 20.—Approximate percentage of time, annually, that the wind blows toward various sectors at Salem, Oreg. Percentages are rounded averages of frequencies determined at altitudes between about 4,000 and 16,000 m; percentages in italics are frequencies at an altitude of about 2,500 m. The height of Mount Hood is 3,424 m. (Compiled from Winds Aloft Summary of the Air Weather Service, U.S. Air Force, for years 1956–70, available from the National Climatic Center, Asheville, N. C.)

fall on the Portland metropolitan area. At altitudes of 4,000 to 16,000 m, which is a reasonable estimate of the heights to which ash could be erupted above the volcano, winds in this region blow toward the west-northwest only about 1 percent of the time annually, according to upper-level wind records at Salem, Oreg. (fig. 20).

# Planning for the Next Eruption

## Planning before an Eruption Occurs

CONTINGENCY plans could be made now by responsible local, State, and Federal agencies for actions to be taken in the event of an eruption of Mount Hood. The primary goals of such plans would be to anticipate hazardous events before they occur and to prepare responses to such events that would mitigate their impact on people and property. An important aspect of these plans would be the determination of lines of authority and areas of responsibility for local, State, and Federal agencies. After such plans are prepared, they could be updated as new information becomes available concerning the volcano, as uses of the land around Mount Hood change, and if comprehensive monitoring systems are permanently installed at the volcano in the future.

## Predicting the Next Eruption

THE last known eruptions of Mount Hood occurred during the middle of the 19th century (Harris, 1976). Such recent eruptions, as well as the thermal activity that has continued to the present at and adjacent to the Crater Rock dome, suggest that molten rock is still present within or beneath Mount Hood, although its existence has not yet been proven. The volcano seemingly was dormant for at least 1,200 years between the Timberline and Old Maid eruptive periods, but only a little more than a century elapsed between the Old Maid period and the activity reported in the mid-1800's. Mount Hood almost surely will erupt again, and possibly in the very near future, but as yet we have no way to predict when the next eruption will occur.

## Warning Signs of an Impending Eruption

VOLCANIC eruptions are often preceded by a variety of phenomena which, if detected and properly interpreted, can warn of an impending eruption. These include:

- Increase in gas emission and temperatures at fumaroles, and changes in composition of gases.
- Rapid melting of snow and unusually high stream discharge not due to weather conditions.
- Local earthquakes.

Earthquakes related to an impending eruption are caused by movement of molten rock into or within a volcano. Such earthquakes initially may be too weak to be detected except by instruments. However, if earthquakes are felt, and if they progressively increase in number and strength over a period of hours or days, an impending eruption should be suspected. Some earthquakes might trigger avalanches of snow or rock from the volcano.

Volcanic eruptions often begin on a small scale and might not be detected if weather conditions were to cause poor visibility. However, andesitic and dacitic volcanoes also have been known to erupt violently with virtually no warning, and with little or no preliminary small-scale activity.

If an eruption began on a relatively small scale, it might first be recognized by one or more of the following:

- Clouds of white or gray steam and "smoke" rising above the volcano.
- A glow in the sky above the volcano at night.
- Loud rumbling noises or sharp explosions.
- Darkening, by tephra, of snow on the volcano's flanks.

Plumes of water vapor vapor ("steam") are often seen rising from the area of Crater Rock when atmospheric conditions are favorable; they sometimes are several hundred meters high. These originate in fumaroles on and adjacent to the Crater Rock dome and should be considered warning signs of a possible eruption only if they increase greatly in volume and persistence.

## What to Do if
## There Are Signs of an Impending Eruption

IF signs of an impending eruption appear, the effects of volcanism might be minimized if people in threatened areas are warned in time. It is suggested that the following actions be taken if warning signs appear, or if an eruption begins without warning:

1. Notify local, State and Federal authorities (such as District Ranger, U.S. Forest Service, County Sheriff offices, State Police, State Division of Emergency Services).
2. Put into effect contingency plans for responding to various kinds of eruptions, including possible restrictions on access to and use of potentially hazardous areas and possible evacuation.
3. Establish a warning system by which residents of threatened areas could be informed of the likelihood of an eruption, the extent and nature of its possible effects, and the contingency plans of governmental agencies for various kinds of eruptions.
4. Establish a volcano watch, by which the volcano would be observed regularly during daylight hours from ground stations and intermittently from aircraft. Seismic and heat-flow conditions of the volcano could be monitored using seismometers and infrared imagery.

Other kinds of geophysical and geochemical monitoring that might be appropriate at Mount Hood and that were utilized at Mount Baker volcano in 1975–76 are described by Frank, Meier, and Swanson (1977).

# REFERENCES CITED

Armstrong, J. E., and Clague, J. J., 1977, Two major Wisconsin litho-stratigraphic units in southwest British Columbia: Canadian Journal of Earth Sciences, v. 14, no. 7, p. 1471-1480.

Armstrong, J. E., Crandell, D. R., Easterbrook, D. J., and Noble, J. B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of American Bulletin, v. 76, no. 3, p. 321-330.

Beaulieu, J. D., 1977, Geologic hazards of parts of northern Hood River, Wasco, and Sherman Counties, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 91, 95 p.

Crandell, D. R., 1971, Postglacial lahars from Mount Rainier volcano, Washington: U.S. Geological Survey Professional Paper 677, 75 p.

Crandell, D. R., and Miller, R. D., 1974, Quaternary stratigraphy and extent of glaciation in the Mount Rainier region, Washington: U.S. Geological Survey Professional Paper 847, 59 p.

Crandell, D. R., and Mullineaux, D. R., 1973, Pine Creek volcanic assemblage at Mount St. Helens, Washington: U.S. Geological Survey Bulletin 1383-A, 23 p.

Crandell, D. R., and Rubin, Meyer, 1977, Late-glacial and postglacial eruptions at Mt. Hood, Oregon: Geological Society of America Abstracts with Programs, v. 9, no. 4, p. 406.

Frank, David, Meier, M. F., and Swanson, D. A., 1977, Assessment of increased thermal activity at Mount Baker, Washington, March 1975-March 1976: U.S. Geological Survey Professional Paper 1022-A, 49 p.

Hammond, P. E., 1973, If Mount Hood erupts: The Ore Bin, v. 35, no. 6, p. 93-102.

Harris, B. L., 1973, Genesis, mineralogy, and properties of Parkdale soils, Oregon: Oregon State University Ph. D. thesis, 174 p.

Harris, S. L., 1976, Fire and ice, the Cascade volcanoes: Seattle, The Mountaineers and Pacific Search Books, 316 p.

Lawrence, D. B., 1948, Mt. Hood's latest eruption and glacier advances: Mazama, v. 30, no. 13, p. 22-29.

Lawrence, D. B., and Lawrence, E. G., 1959, Radiocarbon dating of some events on Mount Hood and Mount St. Helens: Mazama, v. 41, no. 13, p. 10-18.

McBirney, A. R., 1966, Predicting volcanic eruptions: Discovery, v. 27, no. 4, p. 20-25.

Rubin, Meyer, and Alexander, Corrinne, 1960, U.S. Geological Survey radiocarbon dates [Pt.] V: American Journal of Science Radiocarbon Supplement, v. 2, p. 129-185.

Shapiro, Leonard, 1975, Rapid analysis of silicate, carbonate, and phosphate rocks—Revised edition: U.S. Geological survey Bulletin 1401, 76 p.

Stuiver, Minze, 1978, Radiocarbon timescale tested against magnetic other dating methods: Nature, v. 173, no. 5660, p. 271-274.

Trimble, D. E., 1963, Geology of Portland, Oregon, and adjacent areas: U.S. Geological Survey Bulletin 1119, 119 p.

Wilcox, R. E., 1959, Some effects of recent volcanic ash falls, with especial reference to Alaska: U.S. Geological Survey Bulletin 1028-N, p. 409-476.
Williams, Howel, 1960, Volcanic history of the Guatemalan Highlands: California University Publications in Geological Sciences, v. 38, no. 1, p. 1-87.
Wise, W. S., 1966, The last eruptive phase of the Mt. Hood volcano: Mazama, v. 48, no. 13, p. 14-19.
Wise, W. S., 1968, Geology of the Mount Hood volcano—Andesite Conference guidebook: International Upper Mantle Project, Science Report 16-S *and* Oregon Department of Geology and Mineral Industries Bulletin 62, p. 81-98.
______1969, Geology and petrology of the Mt. Hood area—A study of High Cascade volcanism: Geological Society of America Bulletin, v. 80, no. 6, p. 969-1006.

# APPENDICES

# APPENDIX A
## TERMINOLOGY

In this section some technical terms and volcanic processes are explained that might be unfamiliar to readers who do not have a background in geology. The meaning of these terms and knowledge of these processes is necessary to understand the report.

A **volcanic dome** is a mass of solid rock that is formed when pasty lava pushes upward from a vent and is too stiff to flow sideways more than a few tens or hundreds of meters. Movement is chiefly upward in the center of the dome, which causes the sides to become very unstable. Because of this instability, the height of domes generally is limited to only a few hundred meters. Rock masses frequently fall and avalanche as the dome is formed, some triggered by the movement of the dome itself, others by explosions. Avalanches of hot rock debris may move down the volcano's flanks at high speed and reach distances of 10 km or more from their point of origin. Such avalanches of swiftly moving hot rock debris are called pyroclastic flows and form **pyroclastic-flow deposits**.

Pyroclastic flows generally consist of two parts. One is the basal mass of rock debris that moves along the ground, and the other is the turbulent **ash cloud** of fine material that is generated by the basal flow and rises hundreds or thousands of meters above it. When this material settles to the ground, often after being carried downwind from the pyroclastic flow, it forms an ash-cloud deposit. Such a deposit generally is of fine to coarse sand size and consists of particles of minerals and rock. Typically, near-surface winds carry the ash less than 10 km before it drops to the ground. However, because the ash originates in a moving pyroclastic flow, deposition of ash may occur in a relatively narrow band adjacent to the entire length of the pyroclastic flow if the wind direction is at right angles to the direction the pyroclastic flow is moving.

Many deposits formed by pyroclastic flows can be recognized by the presence of wood that has been wholly charred and by a reddish-gray zone as much as 2 m thick at their tops. The presence of charred wood can distinguish a pyroclastic-flow deposit from a glacial deposit or river deposits, but not from a mudflow that was carrying hot rock debris. When such mudflows come to rest, wood fragments in contact with hot boulders can become charred.

Many pyroclastic-flow deposits also contain intricately cracked blocks of rock that have the appearance of a three-dimensional jigsaw puzzle. This type of cracking is referred to as **prismatic jointing**; it results from contraction of the rock while it is cooling.

Since cooling progresses from the outside of the block toward its center, the cracks form at right angles to the surface and progress inward (Wise, 1966). When blocks like these are exposed to the weather, they tend to disintegrate along the joints. The presence of abundant prismatically jointed blocks in a deposit is believed to be evidence that the deposit originated during an eruption and that it was formed either by a hot pyroclastic flow or a hot mudflow. The inference that rock fragments were still hot when they came to rest can be tested by determining, using a magnetometer, the direction of **remanent magnetism** within the rock. The orientation of remanent magnetism in a rock is determined by iron-bearing magnetic minerals in that rock. As a once-molten rock cools through a critical temperature, which can be experimentally determined and is generally at least several hundred degrees Celsius, these minerals acquire a magnetic orientation that is parallel to the Earth's magnetic field. If a volcanic deposit came to rest while rock fragments in it were still above this critical temperature, the orientation of remanent magnetism of the fragments should be uniform and parallel. But if the fragments cooled before they were incorporated in a moving mass, or while the mass was still moving, their magnetic orientation would be random. At Mount Hood, all prismatically jointed blocks that were tested with a magnetometer showed magnetic evidence that they were still hot when the deposit in which they occur was formed.

**Reddish-gray** ("pink") tops on otherwise gray pyroclastic-flow deposits are believed to result form the deposition of finely divided hematite (iron oxide) by hot gases after a pyroclastic flow comes to rest and while it cools (Williams, 1960, p. 13).

A **mudflow** is a mass of water-saturated rock fragments, ranging in size from clay to large boulders, that moves downslope as a fluid. During movement, a mudflow resembles a flowing mass of wet concrete; after it comes to rest and dries out, it looks like bouldery concrete although lacking in cementation. Stones carried by volcanic mudflows can be hot or cold. Mudflows that carry hot rock debris can be generated by pyroclastic flows that melt snow and thus provide water to mix with the hot rock debris. Some relatively small mudflows occur when heavy precipitation saturates masses of loose rock debris lying on steep slopes and when a body of water impounded by a glacier on a volcano is suddenly released.

**Pumice** is a volcanic glass that is very porous (**vesicular**) because of a high gas content when it was erupted. Pumice contrasts with the rock of most domes and lava flows, which is relatively nonporous (**nonvesicular**). **Ash** and **lapilli** are size terms that refer to the diameter of fragments of pumice or other volcanic rock. Ash is restricted to particles less than 4 mm in diameter, and lapilli are fragments 4–32 mm in diameter; larger fragments are called blocks. Ash may consist of volcanic glass, mineral crystals, or fragments of dense rock (lithic ash). Lapilli and blocks generally consist either of pumice or dense rock.

**Tephra** is the term used in this report to describe ash, lapilli, and blocks that are erupted from a vent into the air above a volcano. The individual fragments may consist of pumice or dense rock or a mixture of the two, accompanied by variable amounts of mineral crystals. The term is used here in this restricted sense so as to differentiate the material erupted directly from a vent from the clouds of fine fragmental material generated by pyroclastic flows. Although tephra and ash-cloud deposits have some characteristics in common, they also have some significant differences with respect to potential hazards.

Other geologic terms used in the report are defined below:

**Amphibole**—a group of ferromagnesian rock-forming minerals; includes the minerals hornblende and cummingtonite.

**Andesite**—a fine-grained volcanic rock made up of feldspars and ferromagnesian minerals; typically has a $SiO_2$ content of 54 to about 62 percent (Wise, 1969, p. 973).

**Augite**—a ferromagnesian rock-forming mineral of the pyroxene group.

**Basalt**—a fine-grained volcanic rock made up of feldspars and ferromagnesian minerals; typically has a $SiO_2$ content of less than 54 percent.

**Biotite**—a ferromagnesian rock-forming mineral of the mica group.

**Cirque**—a glacially eroded basin shaped like half a bowl.

**Colluvium**—a deposit formed by earth material that has moved downslope primarily due to gravity.

**Cummingtonite**—a ferromagnesian rock-forming mineral of the amphibole group.

**Dacite**—a fine- to coarse-grained volcanic rock made up of feldspars and ferromagnesian minerals; dacites at Mount Hood typically have $SiO_2$ contents of about 62 to 66 percent (Wise, 1969, p. 973).

**Feldspar**—a large group of generally light-colored rock-forming minerals.

**Ferromagnesian**—an adjective applied to some rocks and generally dark-colored rock-forming minerals that contain iron and magnesium and that include the amphibole, pyroxene, and mica minerals groups and olivine.

**Hornblende**—a ferromagnesian rock-forming mineral of the amphibole group.
**Hypersthene**—a ferromagnesian rock-forming mineral of the pyroxene group.
**Loess**—a deposit of primarily silt-size (0.005–0.05 mm) material laid down by wind.
**Moraine**—rock debris deposited by a glacier; a lateral moraine is formed at the side of a glacier, and a terminal moraine at the downvalley end.
**Olivine**—a ferromagnesian rock-forming mineral especially common in basalt.
**Pyroxene**—a group of ferromagnesian rock-forming minerals that includes augite and hypersthene; distinguished from the amphibole group primarily by chemical composition.
**Till**—an unsorted, unstratified mixture of fine and coarse rock debris deposited by a glacier.

# APPENDIX B

# MEASURED SECTIONS

## MEASURED SECTION 1

Location: In bluff overlooking Salmon River near center SE¼ sec. 25, T. 2 S., R. 6 E., along road to rock quarry, about 0.4 km southwest of U.S. Highway 26.

| | *Thickness in meters* |
|---|---|
| 7. Mudflow of pre-Polallie age: mixture of angular and subangular fragments of light-gray dacite or andesite mostly less than 0.5 cm in diameter in gray sand matrix, massive; oxidized yellowish brown in upper 1 m | 1.4 |
| 6. Mudflow, as above: rock fragments as large as 2 cm in diameter; oxidized yellowish brown in upper 20–30 cm | 1.4 |
| 5. Colluvium: angular fragments of basalt as large as 0.5 cm in diameter in matrix of reddish-brown clay; fragments have weathered rinds as much as 2 mm thick; lenses out to south; as much as | 1.4 |
| 4. Pumiceous ash, yellow; contains cummingtonite, hornblende, and biotite; identified by D. R. Mullineaux (oral commun., 1976) as an ash erupted at Mount St. Helens between about 30,000 and 40,000 years ago | 0.4 |

## MEASURED SECTION 1—Continued

| | Thickness in meters |
|---|---|
| 3. Sand, very fine to coarse, and scattered granules; gray, oxidized yellowish brown in upper 40 cm; contains small fragments of charcoal in upper half | 0.7 |
| 2. Sandy silt (loess?), brown; contains scattered rock granules and small fragments of carbonaceous matter near top | 1.8 |
| 1. Till of Hayden Creek(?) age. Poorly sorted mixture of round and subround cobbles and boulders, some of which are faceted, in compact matrix of gray sand; more than | 2 |

---

## MEASURED SECTION 2

Location: Roadcut and bank of Sandy River at confluence with Zigzag River 0.5 km north of Zigzag, in SE¼SE¼ sec. 33, T. 2 S., R. 7 E.

| | |
|---|---|
| 10. Mudflow of Old Maid(?) age: poorly sorted mixture of angular and subangular rock fragments as much as 10 cm in diameter in compact sand matrix, light brownish gray | 1 |
| 9. Mudflow: poorly sorted mixture of subangular and subround rock fragments as much as 10 cm in diameter in compact sand matrix; dark yellowish brown at top grades down to light olive brown; layer of forest litter 3 cm thick at top contains charred wood fragments less than 200 radiocarbon years old (sample W-3744) | 1.2 |
| 8. Mudflow: poorly sorted mixture of subangular and subround rock fragments as much as 30 cm in diameter in mottled gray and yellowish-brown sand matrix; bed of sand 2-5 mm thick at top contains carbonaceous matter | 0.9 |
| 7. Mudflow: poorly sorted mixture of subangular and subround rock fragments as large as 1 m in diameter in compact matrix of dark-grayish-brown sand; upper 20 cm in yellowish brown | 1.75 |
| 6. Sand, fine, light-olive-brown to grayish-brown, locally reddish-yellow (middle portion not exposed); about | 1.4 |
| 5. Sand, fine, brown; contains scattered lapilli of pumice that contains hypersthene and augite | 0.35 |
| 4. Sand, medium to coarse, gray; contains scattered pebbles and small cobbles | 0.6 |
| 3. Mudflow: poorly sorted mixture of subangular and subround rock fragments as much as 50 cm in diameter in gray sand matrix | 1.5 |
| 2. Sand and pebble, cobble, and boulder gravel | 1.5 |
| 1. Mudflow(?): poorly sorted mixture of subangular and subround rock fragments as much as 1 m in diameter in pinkish-gray sand matrix; contains zones in which matrix is absent; more than | 5 |

## MEASURED SECTION 3

Location: South bank of Sandy River in SE¼SW¼ sec. 33, T. 2 S., R. 7 E., about 1 km west-northwest of Zigzag

| | Thickness in meters |
|---|---|
| 5. Mudflow: poorly sorted mixture of rock fragments as large as 10 cm in diameter in gray sand matrix, lenticular; as much as . | 1 |
| 4. Mudflow: poorly sorted mixture of round to subangular rock fragments as much as 50 cm in diameter in gray sand matrix .. | 1 |
| 3. Mudflow of Timberline age: poorly sorted mixture of subangular and subround rock fragments as much as 1.5 m in diameter in silty sand matrix, mottled yellowish brown and purplish gray; most rock fragments are coated with yellowish brown iron oxides; wood fragment about 20 cm above base had radiocarbon age of 1,780±200 years (sample W-3742) ....... | 5 |
| 2. Sand, medium to very coarse, and granule gravel; contains a few rock fragments as much as 30 cm in diameter; all material appears to be fresh rock débris from Mount Hood, mostly massive, but has local planar bedding and crossbedding; gray, oxidized light yellowish brown in upper 50–60 cm; uppermost 1-3 cm locally humidifed and contains particles of carbonized wood ........................................... | 2–5 |
| 1. Sand and pebble, cobble, and boulder gravel, gray; more than .. | 6 |

## MEASURED SECTION 4

Location: Drainage ditch on south side of parking lot at Mount Hood Meadows, SW¼SW¼ sec. 3, T. 3 S., R. 9 E.

| | Thickness in meters |
|---|---|
| 4. Ash-cloud deposit of Timberline age: fine to very fine lithic ash, pinkish-gray and light-yellowish-brown; has crude planar laminations; contains scattered lapilli of white pumice as much as 4 cm in diameter in lower 10 cm ........................ | 0.4 |
| 3. Ash, lithic, gray; has faint planar laminations; uppermost beds contain vegetative matter .............................. | 0.2 |
| 2. Ash(?), lithic, dark-yellowish-brown; contains much disseminated vegetative matter and, at top, fragments of carbonized wood; appears to represent a soil developed on ash, lenticular; as much as ........................................... | 0.2 |
| 1. Till of Fraser age; more than ............................ | 0.3 |

# APPENDIX C

## CHEMICAL ANALYSES

***Chemical analyses, in percent, of some dacitic rocks erupted at Mount Hood during the last 15,000 years***

[Rapid rock analyses were performed in the laboratories of the U.S. Geological Survey by Z. A. Hamlin using the method described under "single solution" in U.S. Geological Survey Bulletin 1401 (Shapiro, 1975)]

| | Blocks from pyroclastic-flow deposits of Polallie age | | | Block in Timberline pyroclastic flow | Crater Rock dome | Block in Old Maid pyroclastic flow | Young pumice (1859-65?) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| $SiO_2$ | 62.3 | 63.2 | 61.8 | 62.0 | 62.5 | 63.6 | 62.6 |
| $Al_2O_3$ | 16.9 | 16.8 | 17.3 | 16.6 | 17.0 | 16.7 | 16.9 |
| $Fe_2O_3$ | 2.2 | 1.8 | 1.8 | 2.1 | 1.4 | 1.3 | 1.7 |
| FeO | 3.0 | 3.4 | 3.6 | 2.8 | 3.4 | 3.0 | 3.1 |
| MgO | 2.6 | 2.5 | 2.6 | 2.8 | 2.4 | 2.1 | 2.3 |
| CaO | 5.5 | 5.3 | 5.5 | 5.3 | 5.1 | 4.7 | 5.2 |
| $Na_2O$ | 4.3 | 4.3 | 4.1 | 4.2 | 4.8 | 4.6 | 4.2 |
| $K_2O$ | 1.6 | 1.5 | 1.3 | 1.4 | 1.3 | 1.4 | 1.4 |
| $H_2O+$ | .7 | .35 | .82 | .26 | .22 | .14 | 1.1 |
| $H_2O-$ | .15 | .20 | .43 | .09 | .01 | .03 | .45 |
| $TiO_2$ | .81 | .81 | .85 | .78 | .80 | .77 | .77 |
| $P_2O_5$ | .25 | .26 | .25 | .17 | .17 | .16 | .24 |
| MnO | .08 | .08 | .08 | .05 | .06 | .06 | .08 |
| $CO_2$ | .06 | .04 | .02 | .00 | .01 | .00 | .04 |
| **Totals** | 100.45 | 100.54 | 100.45 | 98.55 | 99.17 | 98.56 | 100.08 |

### LOCATIONS FROM WHICH SAMPLES WERE OBTAINED FOR CHEMICAL ANALYSIS

1. About 0.9 km southwest of Tilly Jane Guard Station at head of Polallie Creek valley, about 4 km northeast of the summit of the volcano. Prismatically jointed block of black dacite from pyroclastic-flow deposit about 40 m vertically below top of a succession of deposits of Polallie age.
2. About 0.75 km southwest of Tilly Jane Guard Station at top of north valley wall of Polallie Creek. Prismatically jointed block of light-gray dacite from pyroclastic-flow deposit at top of succession of deposits of Polallie age.
3. On north side of knife-edged ridge adjacent to trail along Newton Creek at about the 5,440-foot-contour line, 4.8 km southeast of the summit of Mount Hood. From deposits of the intermediate fill described on p. 15.
4. Surface of fan formed by pyroclastic-flow deposits of Timberline age on the south side of the volcano along Skyline Trail about 1 km northwest of Timberline Lodge. Prismatically jointed block of gray dacite.
5. Southeast base of dacite dome of Old Maid age in summit crater.
6. Surface of pyroclastic-flow deposit of Old Maid age in White River valley in NW¼NE¼SW¼ sec. 16, T. 3 S., R. 9 E. Prismatically jointed block of gray dacite.
7. At ground surface on terrace formed by pyroclastic-flow deposits of Old Maid age in White River valley, in NW¼ sec. 16, T. 3 S., R. 9 E. Pumice lapilli.

# INDEX

[Italic page numbers indicate major references]

☆ U. S. GOVERNMENT PRINTING OFFICE: 980-679-064

# The GEOLOGIC STORY of the GREAT PLAINS



GEOLOGICAL SURVEY BULLETIN 1493

# The GEOLOGIC STORY of the GREAT PLAINS



GEOLOGICAL SURVEY BULLETIN 1493

# *The GEOLOGIC STORY of The GREAT PLAINS*

DENVER, COLORADO

*But from these immense prairies may arise one great advantage to the United States, viz., the restriction of our population to some certain limits, and thereby a continuation of the union. Our citizens being so prone to rambling, and extending themselves on the frontiers, will, through necessity, be constrained to limit their extent on the west to the borders of the Missouri and the Mississippi, while they leave the prairies, incapable of cultivation, to the wandering and uncivilized Aborigines of the country.*

*Zebulon Pike*

Exploratory Travels Through The Western Territories of North America comprising a voyage from St. Louis, on the Mississippi, to the source of that river, and a journey through the interior of Louisiana and the north-eastern provinces of New Spain. Performed in the years 1805, 1806, and 1807, by order of the Government of the United States. By Zebulon Montgomery Pike. Published by Paternoster-Row, London, 1811: W. H. Lawrence and Company, Denver, 1889. Quotation from pages 230–231, 1889 edition.

# The GEOLOGIC STORY of The GREAT PLAINS

By DONALD E. TRIMBLE

*A nontechnical description of the origin and evolution of the landscape of the Great Plains*

GEOLOGICAL SURVEY BULLETIN 1493

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1980

Library of Congress Cataloging in Publication Data
Trimble, Donald E.
The geologic story of the Great Plains.
(U.S. Geological Survey Bulletin 1493)
Bibliography: p. 50
Includes index.
Supt. of Docs. no.: I 19.3: 1493
1. Geology–Great Plains. I. Title.
II. Series: United States Geological Survey Bulletin 1493.
QE75.B9 no. 1493 [QE71] 557.3s [557.8] 80-607022

---

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

tr to SCI
3-26-97

# CONTENTS

# FIGURES

## FIGURES



## TABLE

# The GEOLOGIC STORY of The GREAT PLAINS

By Donald E. Trimble

## INTRODUCTION

The Great Plains! The words alone create a sense of space and a feeling of destiny—a challenge. But what exactly is this special part of Western America that contains so much of our history? How did it come to be? Why is it different?

Geographically, the Great Plains is an immense sweep of country; it reaches from Mexico far north into Canada and spreads out east of the Rocky Mountains like a huge welcome mat. So often maligned as a drab, featureless area, the Great Plains is in fact a land of marked contrasts and limitless variety: canyons carved into solid rock of an arid land by the waters of the Pecos and the Rio Grande; the seemingly endless grainfields of Kansas; the desolation of the Badlands; the beauty of the Black Hills.

Before it was broken by the plow, most of the Great Plains from the Texas panhandle northward was treeless grassland. Trees grew only along the floodplains of streams and on the few mountain masses of the northern Great Plains. These lush prairies once were the grazing ground for immense herds of bison, and the land provided a bountiful life for those Indians who followed the herds. South of the grasslands, in Texas, shrubs mixed with the grasses: creosote bush along the valley of the Pecos River; mesquite, oak, and juniper to the east.

The general lack of trees suggests that this is a land of little moisture, as indeed it is. Nearly all of the Great Plains receives less than 24 inches of rainfall a year, and most of it receives less than 16 inches. This dryness and the strength of sunshine in this area, which lies mostly between 2,000 and 6,000 feet above sea level, create the semiarid environment that typifies the Great Plains. But it was not always so. When the last continental glacier stood near its maximum extent, some 12,000–14,000 years ago, spruce forest reached southward as far as Kansas, and the Great Plains farther south was covered by deciduous forest. The trees retreated northward as the ice front receded, and the Great Plains has been a treeless grassland for the last 8,000–10,000 years.

For more than half a century after Lewis and Clark crossed the country in 1805–6, the Great Plains was the testing ground of frontier America—here America grew to maturity (fig. 1). In 1805–7, explorer Zebulon Pike crossed the south-central Great Plains, following the Arkansas River from near Great Bend, Kans., to the Rocky Mountains. In later years, Santa Fe traders, lured by the wealth of New Mexican trade, followed Pike's path as far as Bents Fort, Colo., where they turned southwestward away from the river route. Those pioneers who later crossed the plains on the Oregon Trail reached the Platte River near the place that would become Kearney, Nebr., by a nearly direct route from Independence, Mo., and followed the Platte across the central part of the Great Plains.

Although these routes may have seemed long and tedious to those dusty travelers, they provided relatively easy access to the Rocky Mountains and had a continuous supply of fresh water, an absolute necessity in these plains. The minds of those frontiersmen surely were occupied with the dangers and demands of the moment—and with dreams—but the time afforded by the slow pace of travel also gave them ample opportunity for thought about the origins of their surroundings.

Today's traveler, who has less time for contemplation, races past a changing kaleidoscope of landscape. The increased awareness created by this rapidity of change perhaps is even more likely to stimulate questions about the origin of this landscape.


Figure 1.—Index map of the Great Plains showing route of Lewis and Clark and the Santa Fe and Oregon Trails.

For instance, the westbound traveler on Interstate Highway 70 traverses nearly a thousand miles of low, rounded hills after leaving the Appalachians; the rolling landscape is broken only by a few flat areas where glacial ice or small lakes once stood. Suddenly, near Salina, Kans., the observant traveler senses a difference in the landscape. Instead of rounded hills, widely or closely spaced, he sees on the skyline flat surfaces, or remnants of flat surfaces. As he climbs gently westward these broken horizontal lines stand etched against the sky. About 35 miles west of Salina he finds himself on a broad, flat plateau, where seemingly he can see forever. True, in places he descends into stream valleys, but only briefly, for he soon climbs back onto the flat surface.

This plateau surface continues for 300 miles to the west—to within 100 miles of the abrupt front of the Rocky Mountains. East-flowing streams, such as the Smoky Hill, the Saline, the Solomon, and the Republican Rivers and their tributary branches, have cut their valleys into this surface, but these valleys become increasingly shallow and disappear entirely near the western rim of the plateau in eastern Colorado.

The distant peaks of the Rockies are seen for the first time as the traveler approaches the escarpment that forms the western edge of this great plateau. After crossing the escarpment near Limon, Colo., he begins the long gentle descent to Denver, on the South Platte River near the foot of the mountains that loom so awesomely ahead. He has crossed the Great Plains. The distances have been great, but the contrasts have been marked.

Had our traveler selected a different route, either to the north or south, he would have found even greater contrasts, for the Great Plains has many parts, each with its own distinctive aspect. Why should such diverse landscapes be considered parts of the Great Plains? What are their unifying features? And what created this landscape? Has it always been this way? If not, when was it formed? How was it formed?

We will look here at some of the answers to those questions. The history of events that produced the landscape of the Great Plains is interpreted both from the materials that compose the landforms and from the landforms themselves.

As we will see, all landforms are the result of geologic processes in action. These processes determine not only the size and shape of the landforms, but also the materials of which they are made. These geologic processes, which form and shape our Earth's surface, are simply the inevitable actions of the restless interior of the Earth and of the air, water, and carbon dioxide of the atmosphere, aided by gravity and solar heating (or lack of it). They all have helped sculpture the fascinating diversity of the part of our land we call the Great Plains.

## WHAT IS THE GREAT PLAINS?

The United States has been subdivided into physiographic regions that, although they have great diversity within themselves, are distinctly different from each other (fig. 2).

From the Rocky Mountains on the west to the Appalachians on the east, the interior of our country is a vast lowland (see cover) known as the Interior Plains. These plains are bounded on the south by a region of Interior Highlands, consisting of the Ozark Plateaus and the Ouachita province, and by the Coastal Plain. In the Great Lakes region, the Interior Plains laps onto the most ancient part of the continent, the Superior Upland. West of the Great Lakes it extends far to the north into Canada. Certainly the Rocky Mountains are distinctly different from the region to the east, which is the Great Plains. The Great Plains, then, is the western part of the great Interior Plains. The Rocky Mountains form its western margin. But what determines its eastern margin?

During the Pleistocene Epoch or Great Ice Age, huge glaciers formed in Canada and advanced southward into the great, central, low-lying Interior Plains of the United States. (See figure 2.) These glaciers and their deposits modified the surface of the land they covered, mostly between the Missouri and the Ohio Rivers; they smoothed the contours and gave the land a more subdued aspect than it had before they came. This glacially smoothed and modified land is called the Central Lowland. Although the ice sheets lapped onto the northern part, the Great Plains is the largely unglaciated

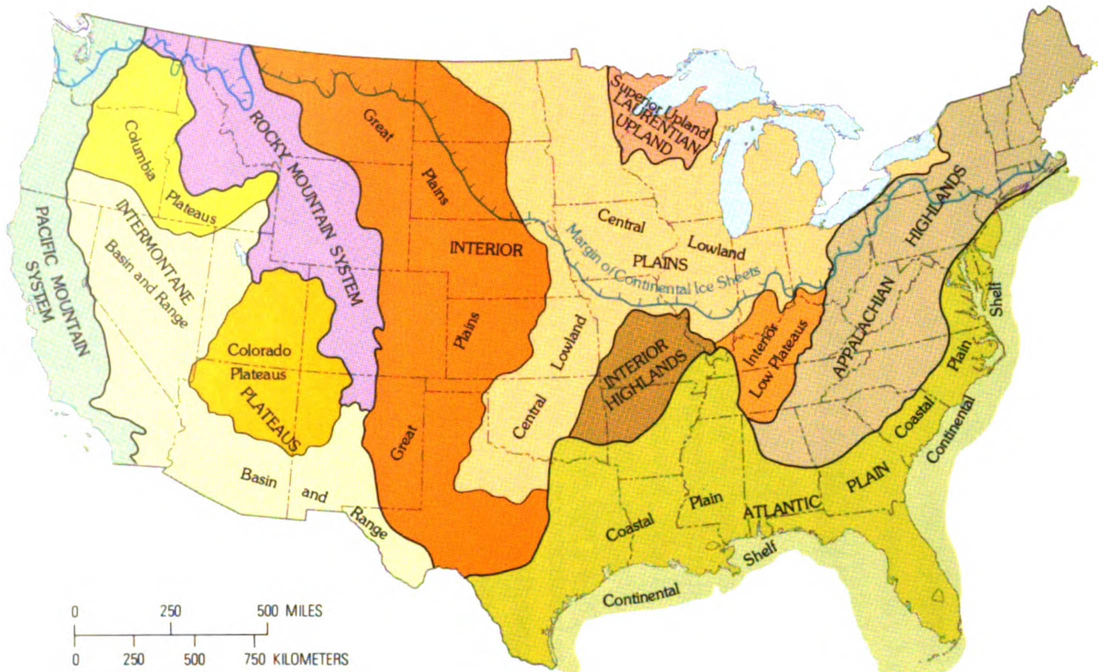



*Figure 2.—Physical divisions of the United States and maximum extent of the continental ice sheets during the Great Ice Age.*

region that extends from the Gulf Coastal Plain in Texas northward into Canada between the Central Lowland and the foot of the Rocky Mountains. Its eastern margin in Texas and Oklahoma is marked by a prominent escarpment, the Caprock escarpment. Its southern margin, where it abuts the Coastal Plain in Texas, is at another abrupt rise or scarp along the Balcones fault zone.

## THE GREAT PLAINS—ITS PARTS

Within the Great Plains are many large areas that differ greatly from adjoining areas (fig. 3). The Black Hills stands out distinctively from the surrounding lower land, and its dark, forested prominence can be seen for scores of miles from any direction. At the southern end of the Great Plains is another, less imposing, forested prominence—the Central Texas Uplift. Most impressive, perhaps, is the huge, nearly flat plateau known as the High Plains, which extends southward from the northern border of Nebraska through the Panhandle of Texas, and which forms the central part of the Great Plains. The east and west rims of the southern High Plains are at high, cliffed, erosional escarpments—the Caprock escarpment on the east and the Mescalero escarpment on the west. The north edge of the High Plains is defined by another escarpment, the Pine Ridge escarpment, which separates the High Plains from a region that has been greatly dissected by the Missouri River and its tributaries. There, several levels of rolling upland are surmounted by small mountainous masses and flat-topped buttes and are entrenched by streams. This region is the Missouri Plateau. The continental glacier lapped onto the northeastern part of the Missouri Plateau and altered its surface.

The South Platte and Arkansas Rivers and their tributaries have similarly dissected an area along the mountain front that is called the Colorado Piedmont, and the Pecos River has excavated a broad valley trending southward from the Sangre de Cristo Mountains in New Mexico into Texas. The Mescalero escarpment separates the Pecos Valley from the southern High Plains (fig. 4). South and east of the Pecos Valley, extending to the Rio Grande and the Coastal Plain, is

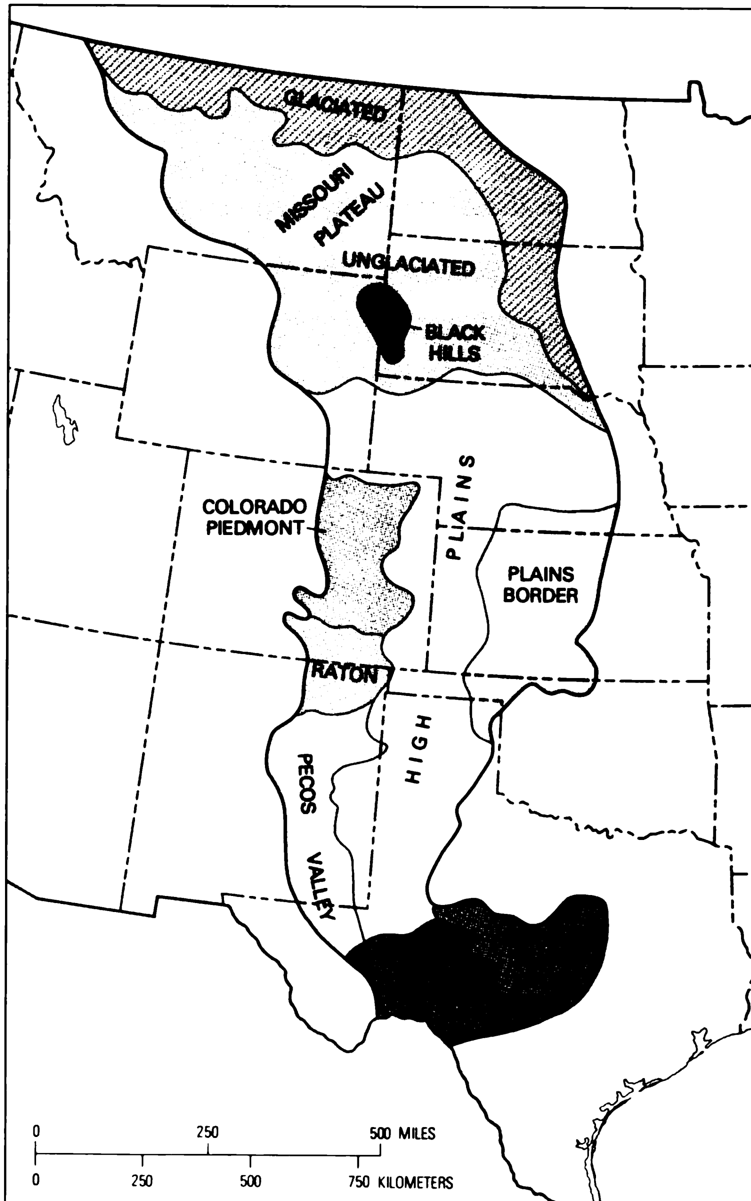
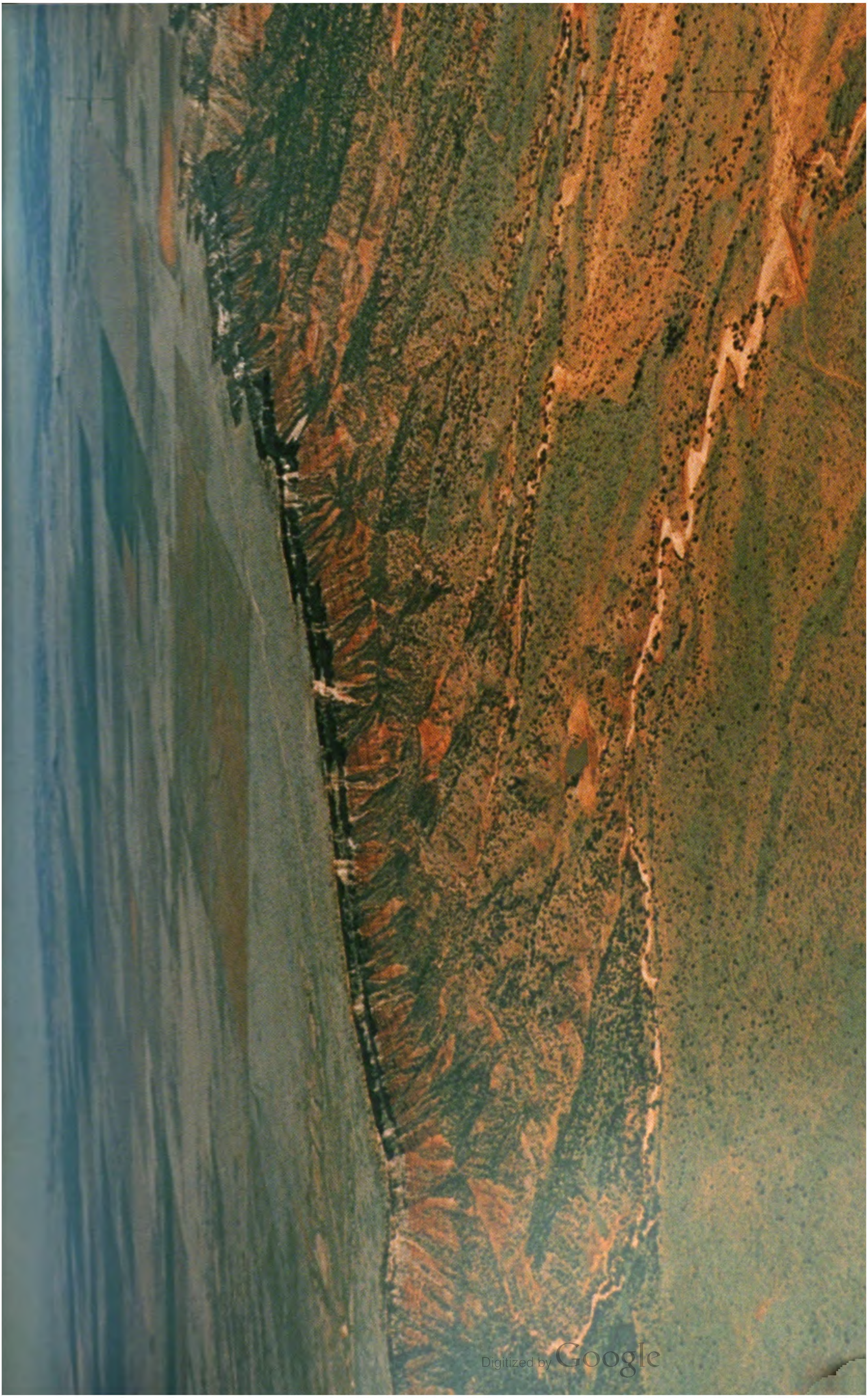



*Figure 3.—The Great Plains province and its sections.*

*Figure 4.—Mescalero escarpment and the southern High Plains (Llano Estacado) south of Tucumcari, N. Mex., Photograph by C. D. Miller, U.S. Geological Survey.*



a broad plateau of bare, stripped, flat-lying limestone layers bearing little but cactus that is called the Edwards Plateau. Green, crop-filled valleys with gently sloping valley walls and rounded stream divides trend eastward from the High Plains of western Kansas and characterize a Plains Border section. And finally, between the Colorado Piedmont on the north and the Pecos Valley on the south, volcanic vents, cinder cones, and lava fields form another distinctive terrain in the part of the Great Plains called the Raton section.

Can such diverse parts of our land have a sufficiently common origin to justify their being considered part of one unified whole—the Great Plains? Probably so, but to understand why, we must examine some of the earlier geologic history of the Great Plains as well as subsequent events revealed in the present landforms. We will find that all parts of this region we call the Great Plains have a similar early history, and that the differences we see are the results of local dominance of certain processes in the ultimate shaping of the landscape, mostly during the last few million years. The distinctive character of the landscape in each section is determined in part by both the early events and the later shaping processes.

## EARLY HISTORY

The Interior Plains, of which the Great Plains is the western, mostly unglaciated part (fig. 2), is the least complicated part of our continent geologically except for the Coastal Plain. For most of the half billion years from 570 million (fig. 5) until about 70 million years ago, shallow seas lay across the interior of our continent (fig. 6). A thick sequence of layered sediments, mostly between 5,000 and 10,000 feet thick, but more in places, was deposited onto the subsiding floor of the interior ocean (table 1). These sediments, now consolidated into rock, rest on a floor of very old rocks that are much like the ancient rocks of the Superior Upland.

About 70 million years ago the seas were displaced from the continental interior by slow uplift of the continent, and the landscape that appeared was simply the extensive, nearly flat floor of the former sea.

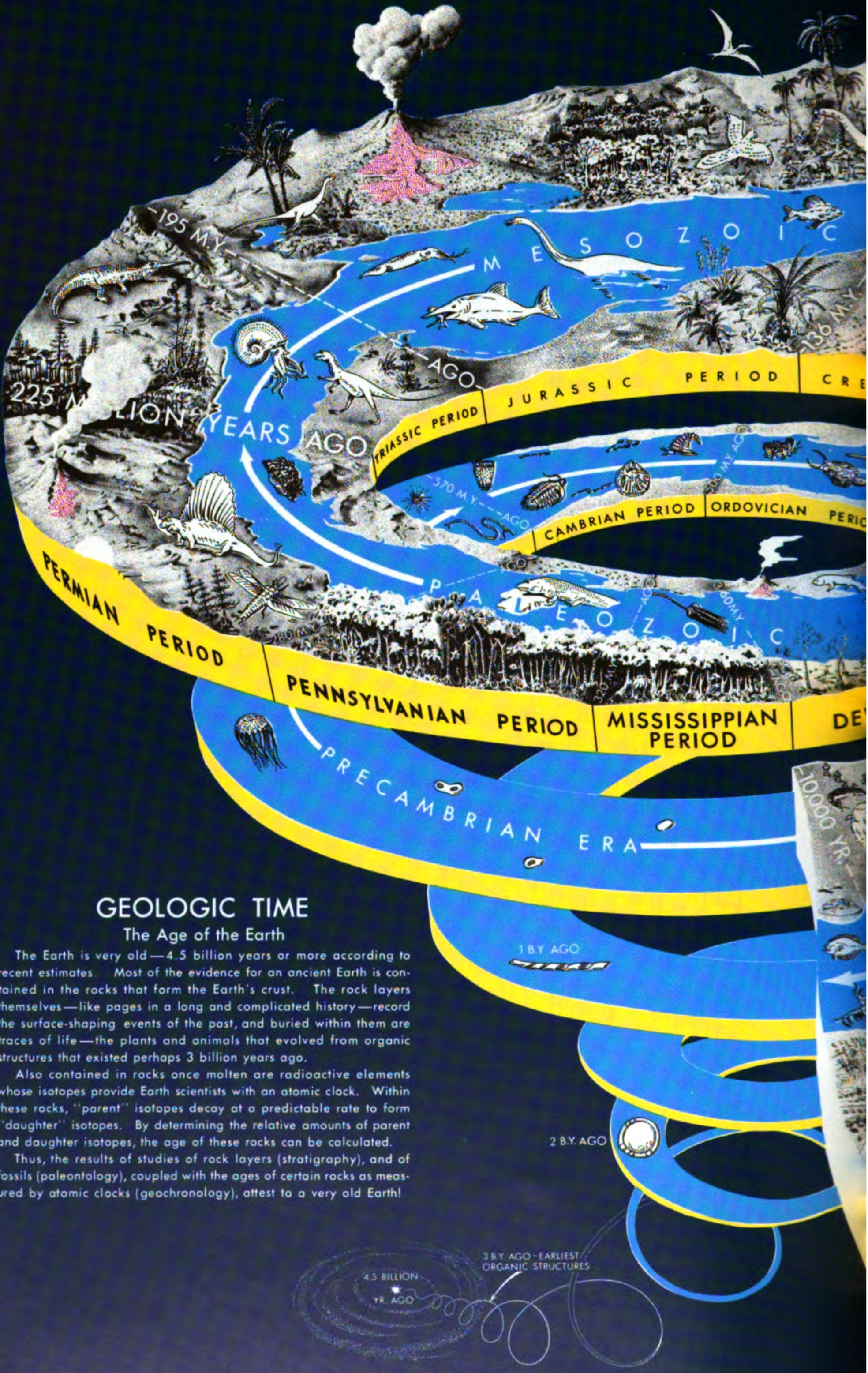
## WARPING AND STREAM DEPOSITION

Most of these rocks of marine origin lie at considerable depth beneath the land surface, concealed by an overlying thick, layered sequence of rocks laid down by streams, wind, and glaciers. Nevertheless, their geologic character, position, and form are exceptionally well known from information gained from thousands of wells that have been drilled for oil. The initial, nearly horizontal position of the layers of rock beneath the Interior Plains has been little disturbed except where mountains like the Black Hills were uplifted about 70 million years ago. At those places, which are all in the northern and southern parts of the Great Plains, the sedimentary layers have been warped up and locally broken by the rise of hot molten rock from depth. Elsewhere in the Interior Plains, however, earth forces of about the same period caused only a reemphasis of gentle undulations in the Earth's crust.

These undulations affected both the older basement rocks and the overlying sedimentary rocks, and they take the form of gentle basins and arches that in some places span several States. (See sketch map, figure 7.) A series of narrow basins lies along the mountain front on the west side of the Great Plains. A broad, discontinuous arch extends southwest from the Superior Upland to the Rocky Mountain front to form a buried divide that separates the large Williston basin on the north from the Anadarko basin to the south.

While the flat-lying layers of the Interior Plains were being only gently warped, vastly different earth movements were taking place farther west, in the area of the present Rocky Mountains. Along a relatively narrow north-trending belt, extending from Mexico to Alaska, the land was being uplifted at a great rate. The layers of sedimentary rock deposited in the inland sea were stripped from the crest of the rising mountainous belt by erosion and transported to its flanks as the gravel, sand, and mud of streams and rivers. This transported sediment was deposited on the plains to form the rocks of the Cretaceous Hell Creek, Lance,

*Figure 5 (overleaf)—Geologic time chart and the progression of life forms. Note Cretaceous* Triceratops, *Oligocene* Titanotheres, *and Miocene* Moropus.



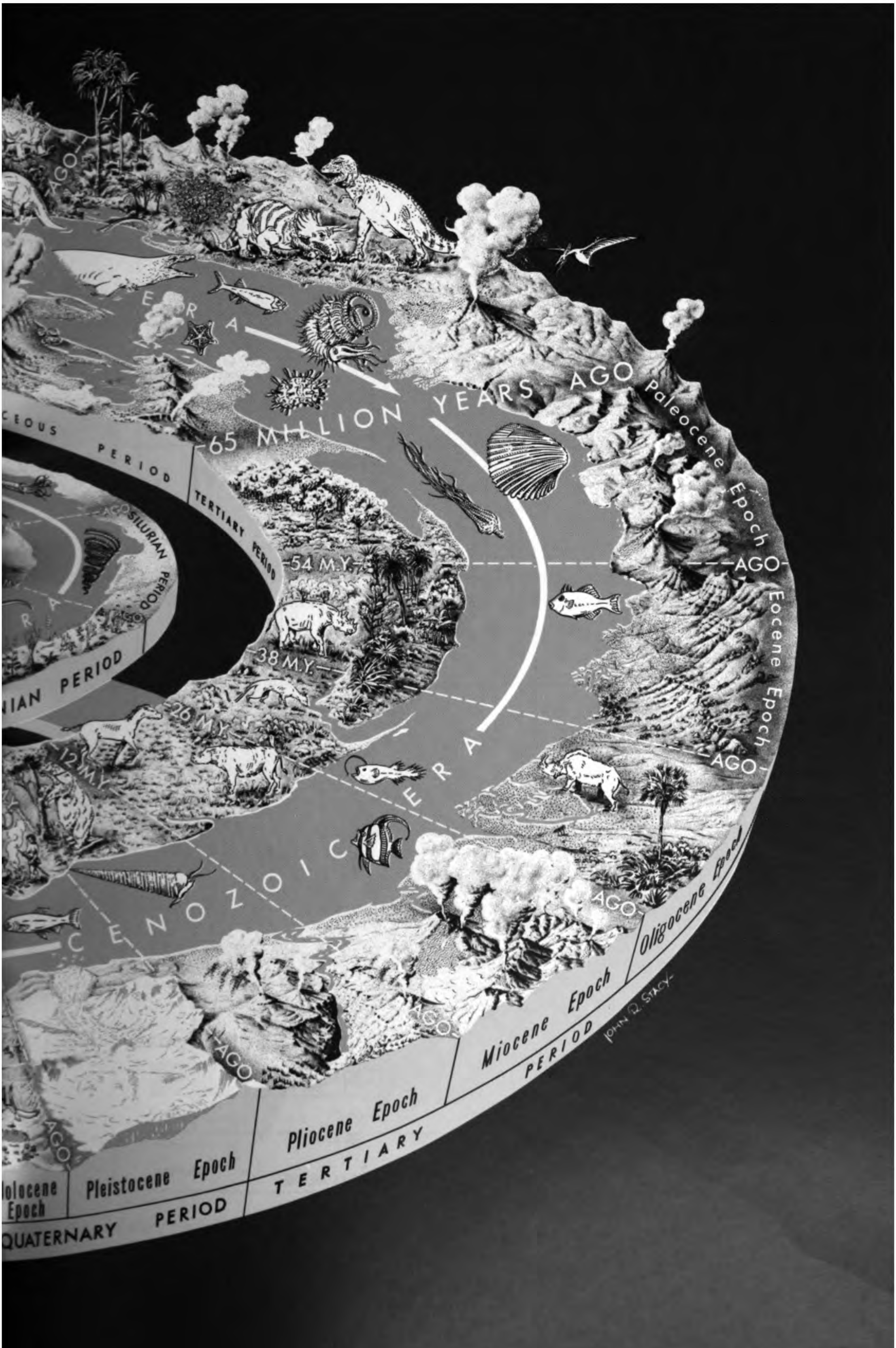

## GEOLOGIC TIME

### The Age of the Earth

The Earth is very old — 4.5 billion years or more according to recent estimates. Most of the evidence for an ancient Earth is contained in the rocks that form the Earth's crust. The rock layers themselves — like pages in a long and complicated history — record the surface-shaping events of the past, and buried within them are traces of life — the plants and animals that evolved from organic structures that existed perhaps 3 billion years ago.

Also contained in rocks once molten are radioactive elements whose isotopes provide Earth scientists with an atomic clock. Within these rocks, "parent" isotopes decay at a predictable rate to form "daughter" isotopes. By determining the relative amounts of parent and daughter isotopes, the age of these rocks can be calculated.

Thus, the results of studies of rock layers (stratigraphy), and of fossils (paleontology), coupled with the ages of certain rocks as measured by atomic clocks (geochronology), attest to a very old Earth!



ERA
65 MILLION YEARS AGO
Paleocene Epoch
AGO
Eocene Epoch
AGO
54 M.Y.
38 M.Y.
26 M.Y.
12 M.Y.
CENOZOIC ERA
TERTIARY PERIOD
CEOUS PERIOD
SILURIAN PERIOD
NIAN PERIOD
Oligocene Epoch
Miocene Epoch
PERIOD
Pliocene Epoch
TERTIARY
Pleistocene Epoch
Holocene Epoch
QUATERNARY PERIOD
JOHN R. STACY


*Figure 6.—Generalized paleogeographic map of the United States in Late Cretaceous time (65 to 80 million years ago), when most of the Great Plains was beneath the sea.*

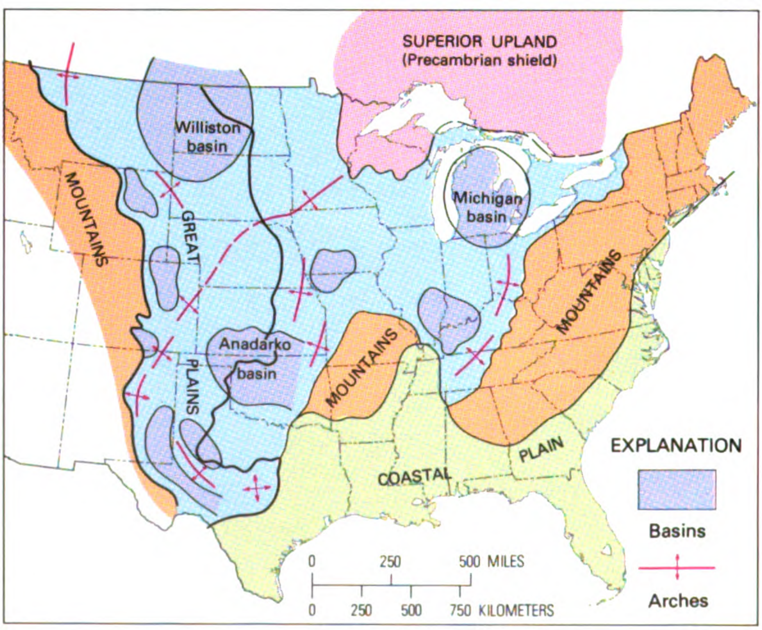



*Figure 7.—Structural setting of the Great Plains. Williston basin and Anadarko basin are separated by a midcontinental arch.*

## *Table 1.—Generalized chart of rocks of the Great Plains*

| | Geologic age | Millions of years ago | Missouri Plateau-Black Hills | High Plains-Plains Border-Colorado Piedmont | Pecos Valley-Edwards Plateau-Central Texas |
|---|---|---|---|---|---|
| Quaternary | Pleistocene | | Glacial deposits, alluvium, and terrace deposits | Alluvium, sand dunes, and loess | Pediment, terrace, and bolson deposits |
| | | 2 | erosional surface | erosional surface | |
| Tertiary | Pliocene | | EROSION | EROSION | |
| | | 5 | | | |
| | Miocene | | Flaxville Gravel and Ogallala Formation<br>Arikaree Formation | Ogallala Formation<br>Arikaree Formation | |
| | | 22-24 | erosional surface | erosional surface | |
| | Oligocene | | White River Group | White River Group | Mostly missing because of erosion or nondeposition |
| | | 37-38 | erosional surface | erosional surface | |
| | Eocene | | Wasatch and Golden Valley Formations | | |
| | | 53-54 | | Dawson Arkose | |
| | Paleocene | | Fort Union Formation | Denver, Poison Canyon, and Raton Formations | |
| | | 65 | | | |
| | Cretaceous | | Hell Creek and Lance Formations<br>Fox Hills Sandstone | Vermejo and Laramie Formations<br>Trinidad and Fox Hills Sandstones | |
| | | | Shales, sandstones, and limestones deposited in Late Cretaceous sea | Shales, sandstones, and limestones deposited in Late Cretaceous sea | |
| | | | Dakota Sandstone and Lakota Formation | Dakota Sandstone | Glen Rose and Edwards Limestones |
| | | 136 | | | |
| | Jurassic | | Sundance Formation, Ellis Group, and Unkpapa Sandstone | Morrison Formation | Jurassic rocks not present |
| | | 190-195 | | | |
| | Triassic | | Dominantly red rocks | Dominantly red rocks | Dominantly red rocks |
| | | 225 | | | |
| | PALEOZOIC | | Paleozoic rocks, undivided | Paleozoic rocks, undivided | Paleozoic rocks, undivided |
| | | 570 | | | |
| | PRECAMBRIAN | | Precambrian rocks, undivided | Precambrian rocks, undivided | Precambrian rocks, undivided |

Laramie, Vermejo, and Raton Formations. Vegetation thrived on this alluvial plain, and thick accumulations of woody debris were buried to ultimately become coal. This lush vegetation provided ample food for the hordes of three-horned dinosaurs (*Triceratops*) that roamed these plains. Their fossilized remains are found from Canada to New Mexico.

As the mountains continued to rise, the eroding streams cut into the old core rocks of the mountains, and that debris too was carried to the flanks and onto the adjoining plains. The mountainous belt continued to rise intermittently, and volcanoes began to appear about 50 million years ago. Together, the mountains and volcanoes provided huge quantities of sediment, which the streams transported to the plains and deposited. The areas nearest the mountains were covered by sediments of Late Cretaceous and Paleocene age (table 1)—the Poison Canyon Formation to the south, the Dawson and Denver Formations in the Denver area, and the Fort Union Formation to the north (fig. 8). Vegetation continued to flourish, especially in the northern part of the Great Plains, and was buried to form the thick lignite and subbituminous coal beds of the Fort Union Formation (fig. 9). The earliest mammals, most of whose remains come from the Paleocene Fort Union Formation, have few modern survivors.

Beginning about 45 million years ago, in Eocene time, there was a long period of stability lasting perhaps 10 million years, when there was little uplift of the mountains and, therefore, little deposition on the plains. A widespread and strongly developed soil formed over much of the Great Plains during this period of stability. With renewed uplift and volcanism in the mountains at the end of this period, great quantities of sediment again were carried to the plains by streams and spread over the northern Great Plains and southeastward to the arch or divide separating the Williston and Anadarko basins (fig. 8). Those sediments form the White River Group, in which the South Dakota Badlands are carved. In addition to the *Titanotheres,* huge beasts with large, long horns on their snouts who lived only during the Oligocene (37 to 22 million years ago), vast herds of camels, rhinoceroses, horses, and tapirs—animals now

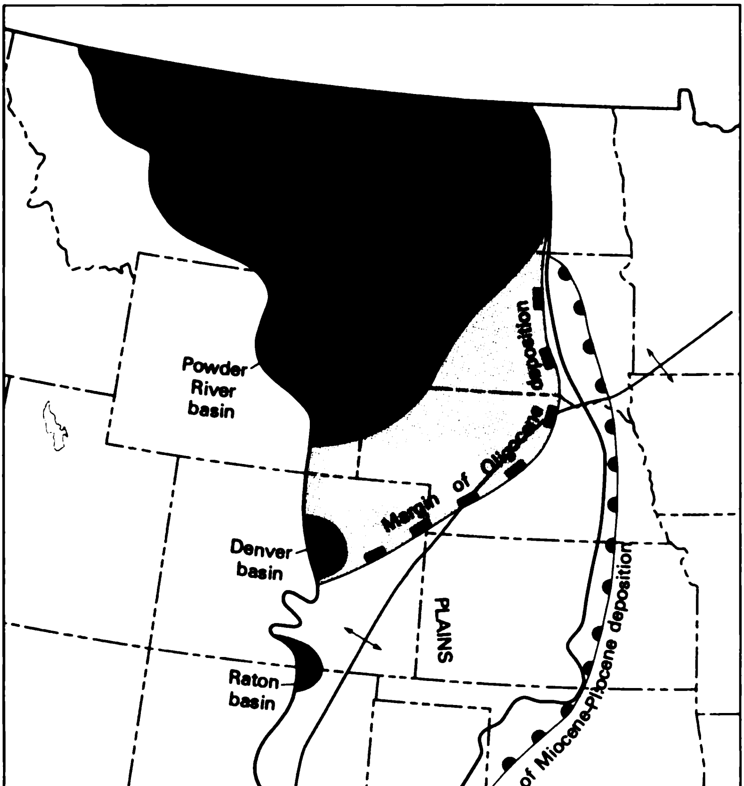



*Figure 8.—Progressive southeastward expansion of areas covered by Paleocene, Oligocene, and Miocene-Pliocene sedimentary deposits.*

*Figure 9.—Big Horn coal strip mine in Fort Union Formation at Acme, Wyo. Photograph by F. W. Osterwald, U.S. Geological Survey.*

found native only on other continents—grazed those Oligocene semiarid grassland plains.

Sometime between 20 and 30 million years ago the streams began depositing sand and gravel beyond the divide, and, for another 10 million years or more, stream sediments of the Arikaree and Ogallala Formations spread over the entire Great Plains from Canada to Texas, except where mountainous areas such as the Black Hills stood above the plains. Between 5 and 10 million years ago, then, the entire Great Plains was an eastward-sloping depositional plain surmounted only by a few mountain masses. Horses, camels, rhinoceroses, and a strange horselike creature with clawed feet (called *Moropus*) lived on this plain.

## SCULPTURING THE LAND

Sometime between 5 and 10 million years ago, however, a great change took place, apparently as a result of regional uplift of the entire western part of the continent. While before, the streams had been depositing sediment on the plains for more than 60 million years, building up a huge thickness of sedimentary rock layers, now the streams were forced to cut down into and excavate the sediments they had formerly deposited. As uplift continued—and it may still be continuing—the streams cut deeper and deeper into the layered stack and developed tributary systems that excavated broad areas. High divides were left between streams in some places, and broad plateaus were formed and remain in other places. The great central area was essentially untouched by erosion and remained standing above the dissected areas surrounding it as the escarpment-rimmed plateau that is the High Plains.

This downcutting and excavation by streams, then, which began between 5 and 10 million years ago, roughed out the landscape of the Great Plains and created the sections we call the Missouri Plateau, the Colorado Piedmont, the Pecos Valley, the Edwards Plateau, and the Plains Border Section. Nearly all the individual landforms that now attract the eye have been created by geologic processes during the last 2 million years. It truly is a young landscape.

## LANDFORMS OF TODAY—

## The surface features of the Great Plains

The mountainous sections of the Great Plains were formed long before the remaining areas were outlined by erosion. Uplift of the Black Hills and the Central Texas Uplift began as the continental interior was raised and the last Cretaceous sea was displaced, 65 to 70 million years ago. They stood well above the surrounding plains long before any sediments from the distant Rocky Mountains began to accumulate at their bases. In southern Colorado and northern New Mexico, molten rock invaded the sedimentary layers between 22 and 26 million years ago. The Spanish Peaks were formed at this time from hot magma that domed up the surface layers but did not break through; the magma has since cooled and solidified and has been exposed by erosion. Elsewhere the magma reached the surface, forming volcanoes, fissures, and basalt flows. A great thickness of basalt flows accumulated at Raton Mesa and Mesa de Maya between 8 and 2 million years ago. Volcanism has continued intermittently, and the huge cinder cone of Capulin Mountain was created by explosive eruption only 10,000 to 4,000 years ago. Most of these volcanic masses were formed before major downcutting by the streams began. Other igneous intrusions and volcanic areas in the northern Great Plains similarly were formed before the streams were incised.

To examine the origin of the present landscape and of the landforms typical of the various sections of the Great Plains, it is convenient to begin with the Black Hills, the Central Texas Uplift, and the Raton section simply because they were formed first—they existed before the other sections were outlined.

## BLACK HILLS

The Black Hills is a huge, elliptically domed area in northwestern South Dakota and northeastern Wyoming, about 125 miles long and 65 miles wide (fig. 10). Rapid City, S. Dak., is on the Missouri Plateau at the east edge of the Black Hills. Uplift caused erosion to remove the overlying cover of marine sedimentary rocks and expose the granite and metamorphic rocks that form the core of the dome. The peaks of the central part of the Black Hills presently are 3,000 to 4,000 feet above the surrounding plains. Harney Peak, with an altitude of 7,242 feet, is the highest point in South Dakota. These central spires and peaks all are carved from granite and other igneous and metamorphic rocks that form the core of the uplift. The heads of four of our great Presidents are sculpted from this granite at Mount Rushmore National Memorial. Joints in the rocks have controlled weathering processes that influenced the final shaping of many of these landforms. Closely spaced joints have produced the spires of the Needles area, and widely spaced joints have produced the rounded forms of granite that are seen near Sylvan Lake (fig. 11).

Marine sedimentary rocks surrounding the old core rocks form well-defined belts. Lying against the old core rocks and completely surrounding them are Paleozoic limestones that form the Limestone Plateau (fig. 10). These tilted layers have steep erosional scarps facing the central part of the Black Hills. Wind Cave and Jewel Cave were produced by ground water dissolving these limestones along joints. These caves are sufficiently impressive to be designated as a national park and a national monument, respectively. Encircling the Limestone Plateau is a continuous valley cut in soft Triassic shale.

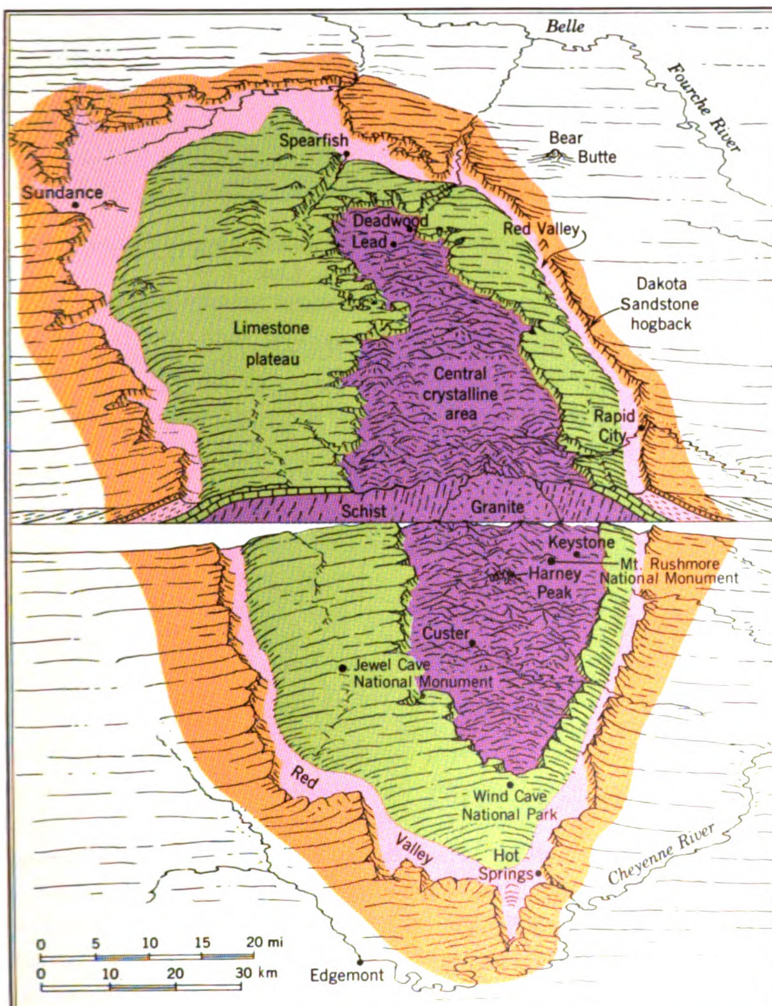



*Figure 10.—Diagram of the Black Hills uplift by A. N. Strahler (Strahler and Strahler, 1978). Used by permission.*

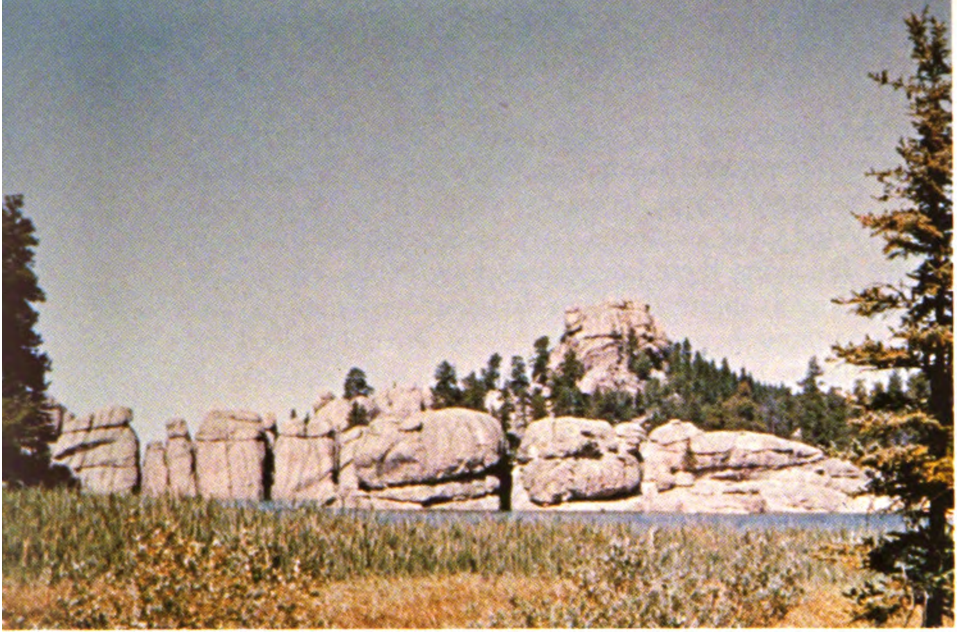


*Figure 11.—Jointed granite rounded by weathering at Sylvan Lake, in the central part of the Black Hills, S. Dak.*

This valley has been called "the Racetrack," because of its continuity, and the Red Valley, because of its color. Surrounding the Red Valley is an outer hogback ridge formed by the tilted layers of the Dakota Sandstone, which are quite hard and resistant to erosion. Streams that flow from the central part of the Black Hills pass through the Dakota hogback in narrow gaps.

The Black Hills, then, is an uplifted area that has been carved deeply but differentially by streams to produce its major outlines. Those outlines have been modified mainly by weathering of the ancient core rocks and solution of the limestone of the Limestone Plateau.

## CENTRAL TEXAS UPLIFT

The domed rocks of the Central Texas Uplift form a topography different from that of the Black Hills. Erosion of a broad, uplifted dome here has exposed a core of old granites, gneisses, and schists, as in the Black Hills, but in the Central Texas Uplift, erosion has produced a topographic basin, rather than high peaks and spires, on the old rocks of the central area. A low plateau surface dissected into rounded ridges and narrow valleys slopes gently eastward from the edge of the central area to an escarpment at the Balcones fault zone, which determines the eastern edge of the Great Plains here. Northwest of the central basin the Colorado River flows in a broad lowland about 100 miles long, but the northern edge of the uplift, forming a divide between the Brazos and the Colorado Rivers, is a series of mesas formed of more resistant sandstone and limestone.

The cutting action of streams, modified or controlled in part by differences in hardness of the rock layers, has been responsible for the landforms of the Central Texas Uplift. Weathering of the old core rocks has softened them sufficiently to permit deeper erosion of the central area, and solution of limestone by ground water has formed such features as Longhorn Caverns, 11 miles southwest of Burnet, Tex.

## RATON SECTION

Volcanism characterizes the Raton section. The volcanic rocks, which form peaks, mesas, and cones, have armored the older sedimentary rocks and protected them from the erosion that has cut deeply into the adjoining Colorado Piedmont to the north and Pecos Valley to the south. The south edge of the Raton section is marked by a spectacular south-facing escarpment cut on the nearly flat-lying Dakota Sandstone. This escarpment is the Canadian escarpment, north of the Canadian River. Northward for about 100 miles, the landscape is that of a nearly flat plateau cut on Cretaceous rock surmounted here and there by young volcanic vents, cones, and lava fields. Capulin Mountain is a cinder cone only 10,000 to 4,000 years old (fig. 12). Near the New Mexico–Colorado border, huge piles of lava were erupted 8 to 2 million years ago onto an older, higher surface on top of either the Ogallala Formation of Miocene age or the Poison Canyon Formation of Paleocene age. (See table 1.) These lava flows formed a resistant cap, which protected the underlying rock from erosion while all the surrounding rock washed away. The result is the high, flat-topped mesas, such as Raton Mesa and Mesa de Maya (fig. 13), that now form the divide between the Arkansas and Canadian Rivers. At Fishers Peak, on the west end of Raton Mesa, about 800 feet of basalt flows rest on the Poison Canyon Formation at about 8,800 feet in altitude. Farther east, on Mesa de Maya, about 400 feet of basalt flows overlie the Ogallala Formation at altitudes ranging from about 6,500 feet at the west end to about 5,200 feet at the east end, some 35 miles to the east. The Ogallala here rests on Cretaceous Dakota Sandstone and Purgatoire Formation, for the Poison Canyon Formation was removed by erosion along the crest of a local uplift before the Ogallala was deposited.

East of the belt of upturned sedimentary layers that form the hogback ridges at the front of the Rocky Mountains, the layered rocks in the Raton Basin have been intruded in many places by igneous bodies, the two largest of which form the Spanish Peaks (fig. 14), southwest of Walsenburg, Colo. These two peaks are formed by igneous bodies that were intruded 26 to 22 million years ago and have since been exposed by removal of the overlying sedimentary rock layers

*Figure 12.—Capulin Mountain National Monument in northeastern New Mexico. This huge cinder cone, which erupted between 4,000 and 10,000 years ago, rises more than 1,000 feet above its base. Photograph by R. D. Miller, U.S. Geological Survey.*

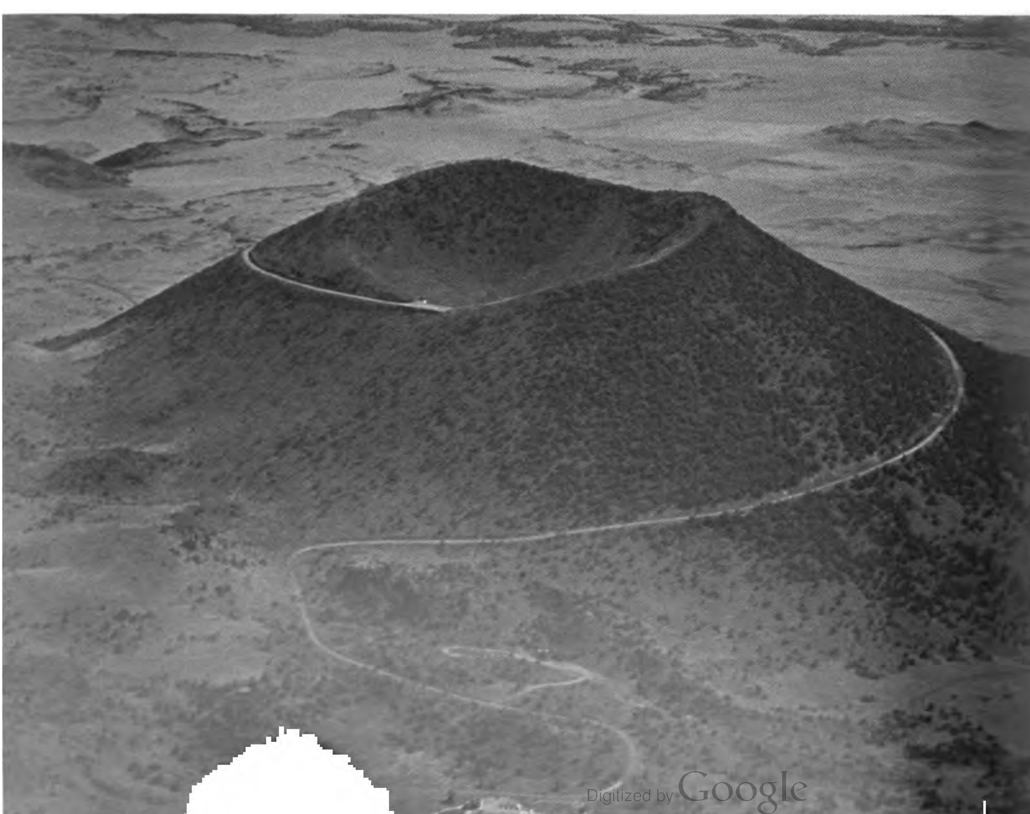


*Figure 13.—Lava-capped Mesa de Maya, east of Trinidad, Colo. Spanish Peaks in left distance. Mesa rises about 1,000 feet above surrounding area. Photograph by R. B. Taylor, U.S. Geological Survey.*

by erosion. Radiating from the Spanish Peaks are hundreds of dikes, nearly vertical slabs of igneous rock that filled fractures radiating from the centers of intrusion. Erosion of the sedimentary layers has left many of these dikes as conspicuous vertical walls of igneous rock that project high above the surrounding land surface. Some of these dikes north of Trinidad, Colo. extend eastward for about 25 miles, almost to the Purgatoire River.

The northern boundary of the Raton section is placed somewhat indefinitely at the northern limit of the area injected by igneous dikes. The eastern boundary of the Raton section is at the eastern margin of the lavas of Mesa de Maya and adjoining mesas, where lava-capped outliers of Ogallala Formation are separated from the Ogallala of the High Plains only by the canyon of Carrizo Creek.

## HIGH PLAINS

At the end of Ogallala deposition, some 5 million years ago, the Great Plains, with the exception of the uplifted and the volcanic areas, was a vast, gently sloping plain that extended from the mountain front eastward to beyond the present Missouri River in some places. Regional uplift of the western part of the continent forced the streams to cut downward; land near the mountains was stripped away by the Missouri, the Platte, the Arkansas, and the Pecos Rivers, and the eastern border of the plains was gnawed away by lesser streams. A large central area of the plain is preserved,

*Figure 14.—Spanish Peaks, southwest of Walsenburg, Colo. Igneous intrusive rocks and many radiating dikes exposed by erosion. Photograph by R. B. Taylor, U.S. Geological Survey.*

however, essentially untouched and unaffected by the streams, as a little-modified remnant of the depositional surface of 5 million years ago. This Ogallala-capped preserved remnant of that upraised surface is the High Plains. In only one place does that old surface still extend to the mountains—at the so-called "Gangplank" west of Cheyenne, Wyo. (fig. 15). In places, as at Scotts Bluff National Monument, Nebr. (fig. 16), small fragments of this surface have been isolated from the High Plains by erosion and now stand above the surrounding area as buttes.

*Figure 15.—Looking east toward Cheyenne at "the Gangplank." Interstate Highway 80 and the Union Pacific Railroad follow the Gangplank from the High Plains in the distance onto the Precambrian rocks (older than 570 m.y.) of the Laramie Mountains in the foreground. Photograph by R. D. Miller, U.S. Geological Survey.*

Figure 16.—Aerial view of Scotts Bluff National Monument, Nebr. Buttes on the south side of the valley of the North Platte River isolated by erosion from High Plains in the background. Highest butte stands about 800 feet above valley floor.

The High Plains extends southward from the Pine Ridge escarpment, near the South Dakota–Nebraska border (fig. 3), to the Edwards Plateau in Texas. The Platte, the Arkansas, and the Canadian Rivers have cut through the High Plains. That part of the High Plains south of the Canadian River is called the Southern High Plains, or the Llano Estacado (staked plain). The origin of this name is uncertain, but it has been suggested that the term Llano Estacado was applied by early travelers because this part of the High Plains is so nearly flat and devoid of landmarks that it was necessary for those pioneers to set lines of stakes to permit them to retrace their routes.

The Llano Estacado is bounded on the west by the Mescalero escarpment (fig. 4) and on the east by the Caprock escarpment. The southern margin with the Edwards Plateau is less well defined, but King Mountain, north of McCamey, Tex., is a scarp-bounded southern promontory of the High Plains. The remarkably flat surface of the Llano Estacado is abundantly pitted by sinks and depressions in the surface of the Ogallala Formation; these were formed by solution of the limestone by rainwater and blowing away or deflation by wind of the remaining insoluble particles. Many of these solution-deflation depressions are aligned like strings of beads, suggesting that their location is controlled by some kind of underlying structure, such as intersections of joints in the Ogallala Formation.

The solution-deflation depressions are less abundant north of the Canadian River, but occur on the High Plains surface northward to the Arkansas River and along the eastern part of the High Plains north of the Arkansas to the South Fork of the Republican River.

Covering much of the northern High Plains, however, are sand dunes and windblown silt deposits (loess) that mantle the Ogallala Formation and conceal any solution-deflation depressions that might have formed. The Nebraska Sand Hills (fig. 17), the largest area of sand dunes in the western hemisphere, is a huge area of stabilized sand dunes that extends from the White River in South Dakota southward beyond the Platte River almost to the Republican River in western Nebraska but only to the Loup River in the northeast part of the High Plains (fig. 18). Loess covers the western

*Figure 17.—Aerial view, looking northwest, of the Nebraska Sand Hills west of Ashby, Nebr.*

High Plains southward from the sand dunes almost to the Arkansas River, and to the South Fork of the Republican in the eastern part. This extensive cover of loess has created a fertile land that makes it an important part of America's wheatlands (fig. 19).

Other, smaller areas of sand dunes lie south of the Arkansas River valley. The only large areas of sand dunes on the Llano Estacado, or Southern High Plains, are along the southwestern margin near Monahans, southwest of Odessa, Tex.

Oil and gas are present in the Paleozoic rocks that underlie the High Plains at depth. Gas fields are ubiquitous in much of the eastern part of the High Plains between the Arkansas and Canadian Rivers. Just south of the Canadian River, at the northeast corner of the Southern High Plains, a huge oil and gas field has been developed near Pampa, Tex. Oil and gas fields also are abundant in the southwestern part of the Southern High Plains, south of Littlefield, Tex.

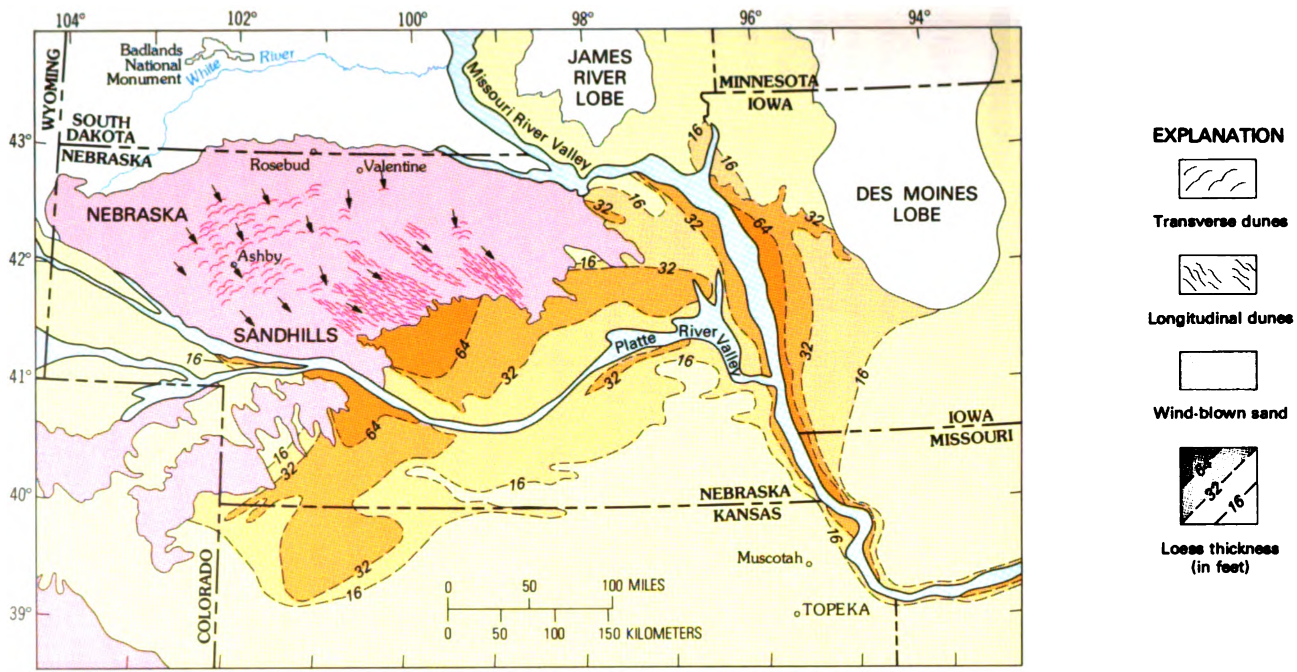



*Figure 18.—The Sand Hills region of Nebraska. Arrows show inferred direction of dune-forming winds. Map from Wright (1970), used by permission.*

*Figure 19.—Little-modified loess plain in southeastern Nebraska. Photograph by Judy Miller.*

The surface of the High Plains, then, has been little modified by streams since the end of Ogallala deposition. It has been raised by regional uplift and pitted by solution and deflation, and large parts of it have been covered by wind-blown sand and silt. It has been drilled for oil and gas and extensively farmed, but it is still a geological rarity—a preserved land surface that is 5 million years old.

## MISSOURI PLATEAU

Beginning about 5 million years ago, regional uplift of the western part of the continent forced streams, which for 30 million years had been depositing sediment nearly continuously on the Great Plains, to change their behavior and begin to cut into the layers of sediment they so long had been depositing. The predecessor of the Missouri River ate headward into the northern Great Plains and developed a tributary system that excavated deeply into the accumulated deposits near the mountain front and carried away huge volumes of sediment from the Great Plains to Hudson Bay. By 2 million years ago, the streams had cut downward to within a few hundred feet of their present level. This region that has been so thoroughly dissected by the Missouri River and its tributaries is called the Missouri Plateau.

About 2 million years ago, after much downcutting had already taken place and river channels had been firmly established, great ice sheets advanced southward from Canada into the United States. (See figure 2.) These continental glaciers formed, advanced, and retreated several times during the last 2 million years. At the north and east margins of the Missouri Plateau they lapped onto a high area, leaving a mantle of glacial deposits covering the bedrock surface and forcing streams to adopt new courses along the margin of ice. The part of the Missouri Plateau covered by the continental glaciers now is referred to as the Glaciated Missouri Plateau. South of the part once covered by ice is the Unglaciated Missouri Plateau.

## Preglacial Drainage

Before the initial advance of the continental ice sheets, the Missouri River flowed northeastward into Canada and to Hudson Bay. Its major tributaries, the Yellowstone and the Little Missouri joined the Missouri in northwestern North Dakota. The east-flowing Knife, Heart, and Cannonball Rivers in North Dakota also joined a stream that flowed northward to Hudson Bay.

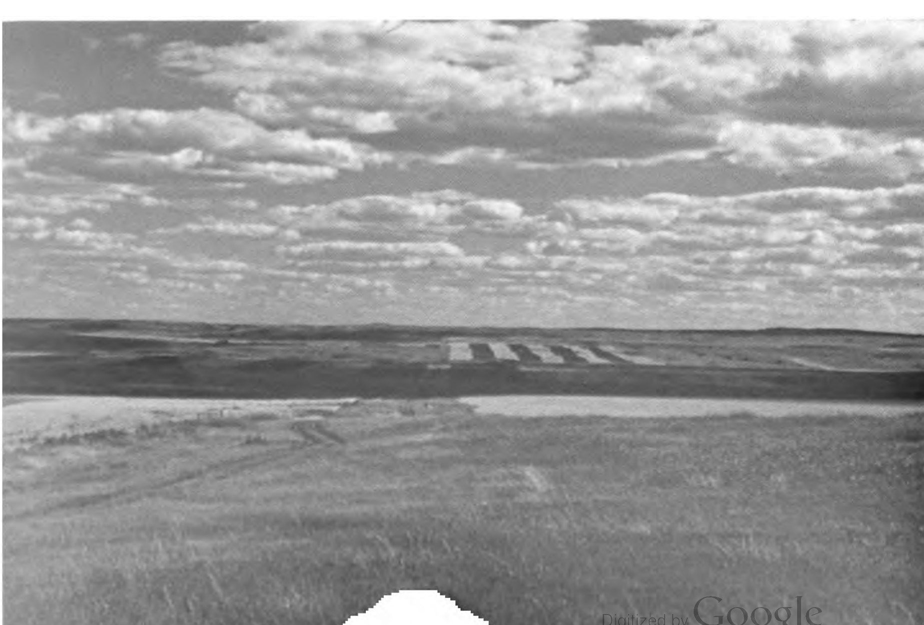
## Glaciated Missouri Plateau

When the continental ice sheets spread southward into northern Montana and the Dakotas, a few isolated areas in Montana stood above the surrounding plain. These are mostly areas that were uplifted by the intrusion of igneous bodies long before the streams began downcutting and carving the land. The northernmost of these isolated mountains, the Sweetgrass Hills, were surrounded by ice and became nunataks, or islands of land, in the sea of advancing ice, which pushed southward up against the Highwood Mountains, near Great Falls, the Bearpaws south of Havre, and the Little Rockies to the east.

Much of the northern part of Montana is a plain of little relief that is the surface of a nearly continuous cover of glacial deposits, generally less than 50 feet thick. This plain has been incised by the east-flowing postglacial Teton, Marias, and Milk Rivers.

In North Dakota, a high area on the east side of the Williston basin acted as a barrier to the advance of the ice, most of which was diverted southeastward. The margin of the ice sheet, however, lapped onto the bedrock high, where it stagnated. Earlier advances moved farthest south; the later advances stopped north of the present course of the Missouri River—their maximum position marked by ridges of unsorted, glacially transported rock debris (till) called terminal moraines. North of the terminal moraines is a distinctive landscape characterized by a rolling, hummocky, or hilly surface with thousands of closed depressions between the hills and hummocks, most of them occupied by lakes. This is the deposit left by the stagnant or dead ice, and it is called dead-ice moraine. The rolling upland in North Dakota that is covered by dead-ice moraine and ridges of terminal moraines from the last glacial advances is called the Coteau du Missouri (fig. 20). A gently sloping scarp, several hundred feet high and mostly covered by glacial deposits (referred to collectively as drift), separates the Coteau du Missouri from the lower, nearly flat, drift-covered plains of the Central Lowland to the east. This escarpment, which is called the Missouri escarpment, is virtually continuous across the State of North Dakota southward into South Dakota. The base of the Missouri escarpment is the eastern boundary of the Great Plains in these northern states.

*Figure 20.—Ground moraine on the Coteau du Missouri, northwestern North Dakota. Photograph by R. M. Lindvall, U.S. Geological Survey.*



The advancing ice front blocked one after another of the northward-flowing streams of the region, diverting them eastward along the ice front. Shonkin Sag, north of the Highwood Mountains near Great Falls, Mont., is an abandoned diversion channel of the Missouri River, occupied when the ice front stood close to the north slopes of the Highwoods. Much of the present course of the Missouri River from Great Falls, Mont., to Kansas City, Mo., was established as an ice-marginal channel, and the east-flowing part of the Little Missouri River in North Dakota was formed in the same way. These valleys were cut during the last 2 million years.

The north-flowing part of the Little Missouri River and the east-flowing courses of the Knife, Heart, and Cannonball Rivers in North Dakota are for the most part older, preglacial courses. The Little Missouri was dammed by the ice, and its waters impounded to form a huge lake during the maximum stand of the ice, but the deposits of this glacial lake are few and make no imprint on the landscape.

The valley of the east-flowing, glacially diverted part of the Little Missouri River, however, is markedly different from that of the north-flowing preglacial river. It is much narrower and has steeper walls than the old valley. Because it is younger, it is little modified, except by huge landslides that have affected both walls of the valley. Tremendous rotated landslide blocks in the North Unit of Theodore Roosevelt National Memorial Park are some of the best examples of the slump type of landslide to be seen anywhere (fig. 21).

Melting ice at the front of the glaciers provided large volumes of meltwater that flowed across the till-mantled surface in front of the glacier as it melted back toward Canada. This meltwater took many courses to join the glacially diverted Missouri River, and these sinuous meltwater channels wind across the dead-ice moraine and the older, less hummocky ground moraine between the Coteau du Missouri and the Missouri River. Locally the sediment carried by the meltwater streams was banked against a wall of ice to form a small hill of stratified drift that is called a kame. Streams flowing in tunnels beneath the ice formed sinuous, ridgelike deposits called eskers, and in places the meltwater deposits form broad flat areas called outwash plains.

*Figure 21.—Rotated slump blocks in huge landslide, North Unit of Theodore Roosevelt National Memorial Park, N. Dak. Note that layering of Fort Union Formation in cliffs on skyline, where landslide originated, is horizontal.*

This rather limited variety of landforms, then, characterizes the landscape of the Glaciated Missouri Plateau. The landforms themselves are testimony to their glacial origin and to the great advances of the continental ice sheets. This is a stream-carved terrain that has been modified by continental glaciers and almost completely covered by a thick blanket of glacially transported and deposited rock debris, locally hundreds of feet thick. Subsequent stream action has not altered the landscape greatly.

## Unglaciated Missouri Plateau

Beyond the limits reached by the ice of the continental glaciers, the Unglaciated Missouri Plateau displays the greatest variety of landforms of any section of the Great Plains. In western Montana, many small mountain masses rise above the general level of the plateau, including the Highwood, Bearpaw, and Little Rocky Mountains near the margin of the glaciated area, and the Judith, Big Snowy, Big Belt, Little

*Figure 22.—The Highwood Mountains seen from the Little Belt Mountains, Mont. Photograph by I. J. Witkind, U.S. Geological Survey.*

Belt, Castle, and Crazy Mountains farther south (fig. 22). Many of these, such as the Crazy, Castle, Judith, and Big Snowy Mountains, are areas uplifted by large, deeply rooted, intrusive igneous bodies called stocks, which have been exposed by subsequent erosion of the arched overlying sedimentary rock layers. Some, such as the Highwood and Bearpaw Mountains, are predominantly piles of lava flows, although in the Bearpaws the related intrusive bodies of igneous rock form a part of the mountains. The Big and Little Belt Mountains were formed by mushroom-shaped intrusive igneous bodies called laccoliths, which have spread out and domed between layers of sedimentary rocks. A number of igneous bodies also intrude the rocks of the Missouri Plateau around the periphery of the Black Hills. Devils Tower, the first feature to be designated a National Monument, is the best known of these igneous rock features (fig. 23).

The uplift and volcanism that formed these mountains took place before the streams began to cut downward and segment the Great Plains. The mountains had been greatly dissected before the advent of the Great Ice Age, when alpine glaciers formed on the Castle and the Crazy Mountains and flowed down some of the stream-cut valleys. Alpine glacial features such as cirques, in the high parts of the mountains, and glacially modified U-shaped valleys (fig. 24) are impressive evidence of this glaciation.

The Missouri River and its tributaries—the Sun, Smith, Judith, Musselshell, and Yellowstone Rivers in Montana and the Little Missouri River in North Dakota—have cut down

*Figure 23.—Devils Tower National Monument, Wyo. An igneous intrusive body exposed by erosion. Photograph by F. W. Osterwald, U.S. Geological Survey.*

*Figure 24.—U-shaped, glaciated valley of Big Timber Creek, Crazy Mountains, Mont. Photograph by W. C. Alden, 1921, U.S. Geological Survey.*

into the Missouri Plateau, cut broad upland surfaces at many levels, and established confined valleys with valley floors flanked by terrace remnants of older floodplains. Locally, high buttes that are remnants of former interstream divides rise above the uplands. Large lakes also were formed in most of these tributary valleys because of damming by the continental ice sheets.

West of the Black Hills, in Wyoming, the Tongue River and the Powder River have excavated the Powder River Basin and produced similar features (fig. 25). The east-flowing tributaries of the Missouri River—the Knife, Heart, and Cannonball Rivers in North Dakota and the Grand, Moreau, Belle Fourche, Cheyenne, Bad, and White Rivers in South Dakota—similarly have shaped the landscape.

Most of these rivers flow in broad, old valleys, established more than 2 million years ago, before the first advance of the continental ice sheets. Some of these valleys have been widened by recession of the valley walls by badland development. Badlands are formed by the cutting action of rivulets and rills flowing down over a steeply sloping face of soft, fine-grained material composed mainly of clay and silt. The intricate carving by thousands of small streams of water produces the distinctive rounded and gullied terrain we call badlands. Badlands National Monument in South Dakota

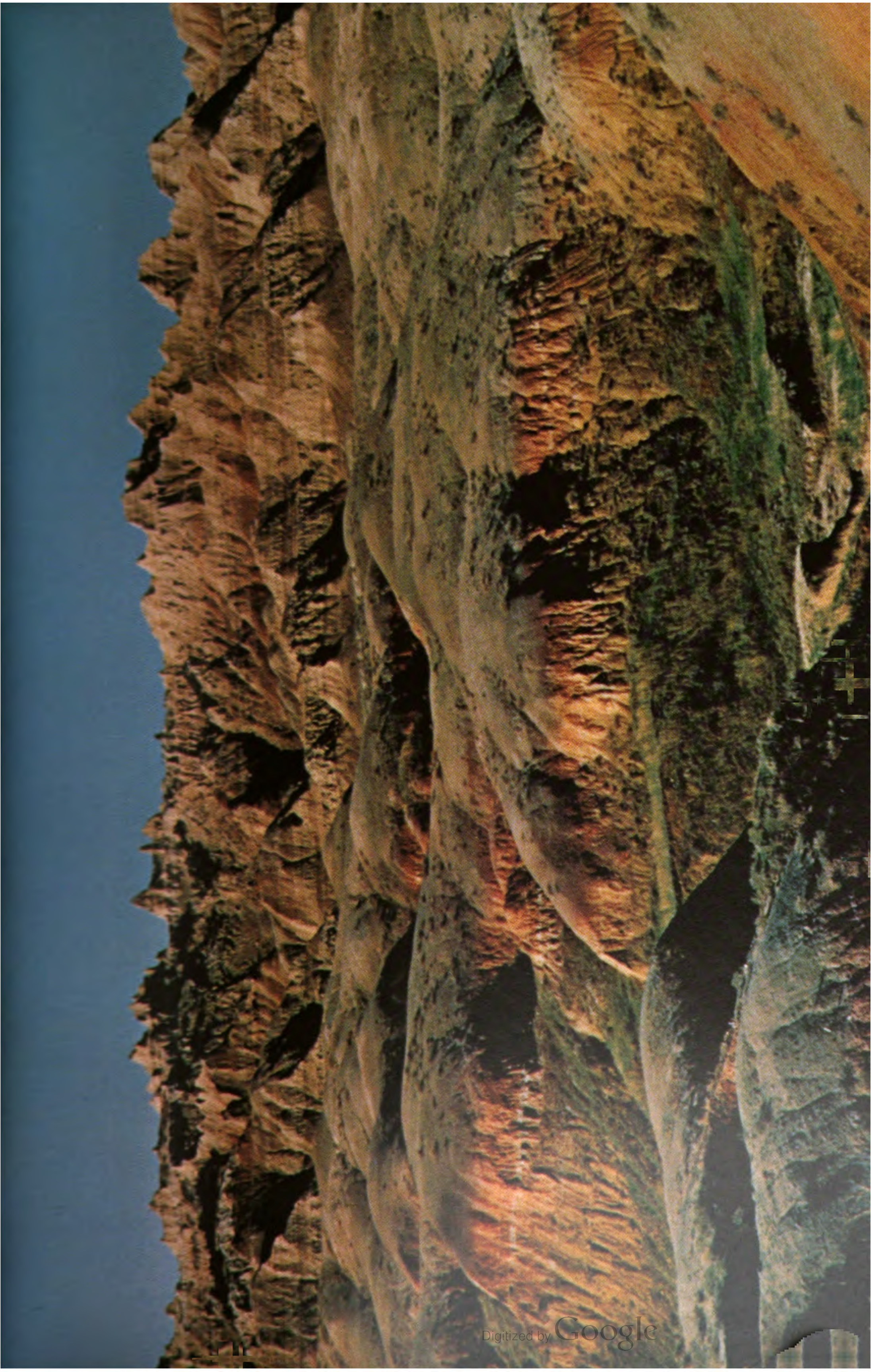
*Figure 25.—View northeast across the Deckers coal mine and the Tongue River in the Powder River Basin, southeastern Montana. Typical terrain of unglaciated Missouri Plateau. Small mesas with cliffed escarpments on capping layer of resistant sandstone, such as those in the foreground, are common. Coal mine is about 1 mile across. Photograph by R. B. Taylor, U.S. Geological Survey.*

(fig. 26) has been established in the remarkable badlands terrain cut into the White River Group along the north valley wall of the White River, and the South Unit of Theodore Roosevelt National Memorial Park is in the colorful badlands of the Little Missouri River, formed on the Fort Union Formation (fig. 27).

The White River also has cut a steep scarp along its southern wall that is called the Pine Ridge escarpment. This escarpment defines the boundary between the Missouri Plateau and the High Plains here.

The landscape of the Unglaciated Missouri Plateau has been determined largely by the action of streams, but in some areas igneous intrusions and volcanoes have produced small mountain masses that interrupt the plain, and valley glaciers have modified the valleys in some of these mountains.

*Figure 26.—Badlands in Badlands National Monument, S. Dak. Photograph by W. H. Raymond, III, U.S. Geological Survey.*



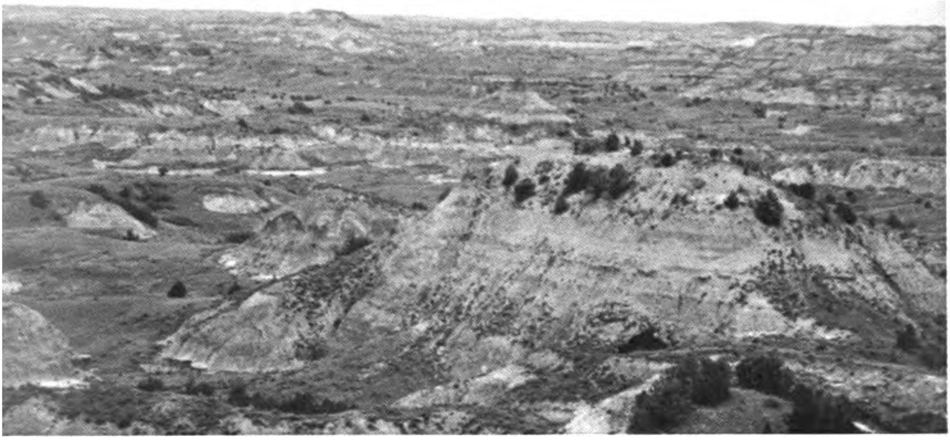


*Figure 27.—Badlands of the Little Missouri River in South Unit of Theodore Roosevelt National Memorial Park, N. Dak. View looking northwest from Painted Canyon Overlook along Interstate Highway 94, west of Belfield.*

## THE COLORADO PIEDMONT

The Colorado Piedmont lies at the eastern foot of the Rockies, (fig. 1) largely between the South Platte River and the Arkansas River. The South Platte on the north and the Arkansas River on the south, after leaving the mountains, have excavated deeply into the Tertiary (65- to 2-million-year-old) sedimentary rock layers of the Great Plains in Colorado and removed great volumes of sediment. At Denver, the South Platte River has cut downward 1,500 to 2,000 feet to its present level. Three well-formed terrace levels flank the river's floodplain, and remnants of a number of well-formed higher land surfaces are preserved between the river and the mountains. Along the western margin of the Colorado Piedmont, the layers of older sedimentary rock have been sharply upturned by the rise of the mountains. The eroded edges of these upturned layers have been eroded differentially, so that the hard sandstone and limestone layers form conspicuous and continuous hogback ridges (fig. 28). North of the South Platte River, near the Wyoming border, a scarp that has been cut on the rocks of the High Plains marks the northern boundary of the Colorado Piedmont. Pawnee Buttes (fig. 29) are two of many butte outliers of the High Plains rocks near that scarp, separated from the High Plains by erosion as is Scotts Bluff, farther north in

Nebraska. To the east, about 10 miles northwest of Limon, Colo., Cedar Point forms a west-jutting prow of the High Plains.

The Arkansas River similarly has excavated much of the Tertiary piedmont deposits and cut deeply into the older Cretaceous marine rocks between Canon City and the Kansas border. The upturned layers along the mountain front, marked by hogback ridges and intervening valleys, continue nearly uninterrupted around the south end of the Front Range into the embayment in the mountains at Canon City. Skyline Drive, a scenic drive at Canon City, follows the crest of the Dakota hogback for a short distance and provides a fine panorama of the Canon City embayment.

Extending eastward from the mountain front at Palmer Lake, a high divide separates the drainage of the South Platte River from that of the Arkansas River. The crest of the divide north of Colorado Springs is generally between 7,400 and 7,600 feet in altitude, but Interstate Highway 25 crosses it at about 7,350 feet, nearly 1,500 feet higher than Colorado Springs and more than 2,000 feet higher than Denver. From the crest of the divide to north of Castle Rock, resistant Oligocene Castle Rock Conglomerate (which is equivalent to

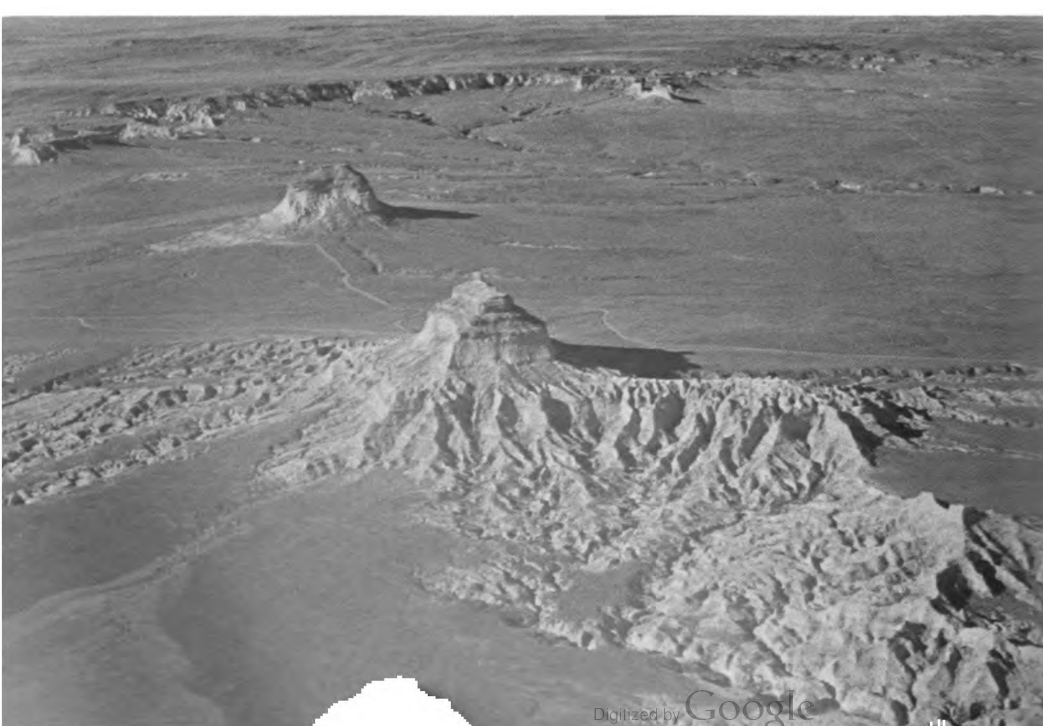
*Figure 28.—Hogback ridges along the Front Range west of Denver, Colo. South Platte River emerges from the mountains and cuts through hogbacks in middle distance. Photograph courtesy of Eugene Shearer, Intrasearch, Inc.*

part of the White River Group of the High Plains) is preserved in many places and forms a protective caprock on mesas and buttes. This picturesque part of the Colorado Piedmont looks quite different from the excavated valleys of the South Platte and Arkansas Rivers.

Much of the terrain in the two river valleys has been smoothed by a nearly continuous mantle of windblown sand and silt. Northwesterly winds, which frequently blow with near-hurricane velocities, have whipped fine material from the floodplains of the streams and spread it eastward and southeastward over much of the Colorado Piedmont. Well-formed dunes are not common, but alined gentle ridges of sand and silt and abundant shallow blowout depressions inform us of the windblown origin of this cover.

In the Colorado Piedmont, then, the erosional effects of streams are the most conspicuous features of the landscape, but these are enhanced by the steep tilting of the layered rocks along the western margin as a result of earth move-

*Figure 29.—Pawnee Buttes in northeastern Colorado. Buttes isolated by erosion from High Plains in the background. Ogallala Formation caps top of Buttes. White River Group forms lower part. The top of the highest butte is about 240 feet above the saddle between the two buttes. Photograph by R. D. Miller, U.S. Geological Survey.*



ment and modified by the nearly ubiquitous products of wind action, which have softened the landscape with a widespread cover of windblown sand and silt.

## PECOS VALLEY

South of the land of volcanic rocks that is the Raton section, the Pecos River has cut a broad valley from the Sangre de Cristo Mountains, in New Mexico, southward to the Rio Grande, and has removed the piedmont cover of Ogallala Formation and cut deeply into the underlying rocks. The Ogallala Formation capping the High Plains to the east forms a rimrock at the top of the sharp Mescalero escarpment, which is the eastern boundary of the Pecos Valley. (See figure 4.) The western boundary of the Pecos Valley is the eastern base of discontinuous mountain ranges.

The great thickness of Tertiary deposits that formed on the northern Great Plains did not accumulate here, and the Pecos River has cut its valley into the older marine sedimentary rocks. The rocks underlying the surface of much of the Pecos Valley are upper Paleozoic limestones.

The soluble nature of limestone is responsible for some of the most spectacular features of the landscape in the Pecos Valley. For about 10 miles north and 50 miles south of Vaughn, N. Mex., collapsed solution caverns in upper Paleozoic limestones have produced an unusual type of topography called karst. Karst topography is typified by numerous closely spaced sinks or closed depressions, some of which are very deep holes, caused by the collapse of the roof of a cave or solution cavity into the underground void, leaving hills, spines, or hummocks at the top of the intervening walls or ribs separating the depressions.

Although the karst in the vicinity of Vaughn is perhaps the most conspicuous solution phenomenon, sinks and caves are common throughout the Pecos Valley. At Bottomless Lakes State Park east of Roswell, N. Mex., seven lakes occupy large sinkholes caused by the solution of salt and gypsum in underlying rocks.

The most spectacular example of solution of limestone by ground water is Carlsbad Caverns, N. Mex., one of the most beautiful caves in the world. This celebrated solution cavity is preserved in a national park.

The Pecos River along much of its present course flows in a vertical-walled canyon with limestone rims. The Canadian River, flowing eastward from the Sangre de Cristo Mountains, has cut a deep canyon along the northern part of the Pecos Valley section. The sharp rims of the Dakota Sandstone at the Canadian escarpment, north of the Canadian River, form the northern boundary of the Pecos Valley section.

The sharp, northeast-trending broken flexure called the Border Hills that is crossed by U.S. Highway 70–380 about 20 miles west of Roswell is a unique landform of the Pecos Valley. This markedly linear upfolded (anticlinal) structure forms a ridge more than 30 miles long and about 200 feet high.

As in the Colorado Plateau, windblown sand and silt mantle the landscape in many places, but the greatest accumulations are along the base of the Mescalero escarpment at the northeast and southeast corners of the Pecos Valley section.

East of the Pecos River, in the southeast part of the Pecos Valley, the underlying rocks have yielded much oil and potash. Oil fields are common east of Artesia and Carlsbad, and potash is mined east of Carlsbad.

The Pecos and Canadian Rivers and their tributaries have created the general outline of the landscape of the Pecos Valley, but underground solution of limestone by ground water and the collapse of roofs of these cavities have contributed much detail to the surface that characterizes the Pecos Valley today.

## EDWARDS PLATEAU

South of the Pecos Valley section, the Pecos River continues its journey to the Rio Grande in a steep-walled canyon cut 400 to 500 feet below the level of a plateau surface of Cretaceous limestone from which little has been stripped except a thin Tertiary cover of Ogallala Formation (fig. 30). To the east, the plateau has been similarly incised by the Devils River and the West Nueces and Nueces Rivers. East of the Nueces to the escarpment formed by the Balcones fault zone, the southern part of the Edwards Plateau has been intricately dissected by the Frio, Sabinal, Medina, Guadalupe, and

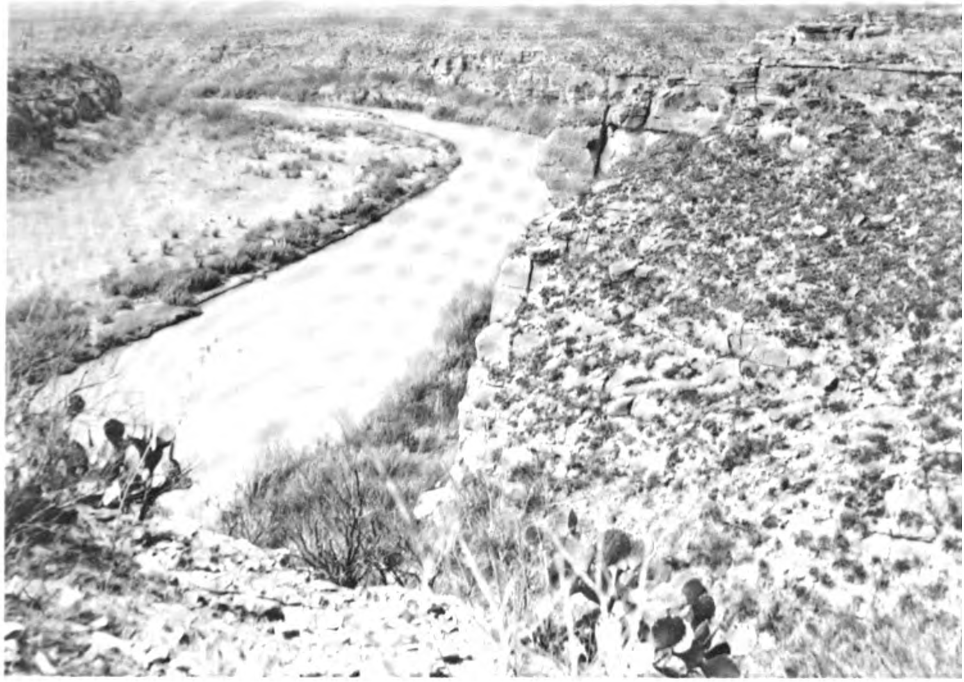


*Figure 30.—Rio Grande and the flat-lying limestone layers of the Edwards Plateau downstream from the mouth of the Pecos River. Mexico on the left side of picture. Photograph by V. L. Freeman, U.S. Geological Survey.*

Pedernales Rivers and their tributary systems. San Antonio and Austin, Tex., are located on the Coastal Plain at the edge of the Balcones fault zone.

The Pecos River, and to a lesser extent the Devils and Nueces Rivers, particularly in their lower courses, have entrenched themselves deeply in the plateau in remarkable meandering courses of a type that is usually found only in broad, low-lying floodplains. These stream courses reflect the stream environment prior to regional uplift.

Sinkholes pit the relatively undissected limestone plateau surface in the northeast part of the Edwards Plateau, and some underground solution cavities in the limestone are well-known caves, such as the Caverns of Sonora, southwest of Sonora, Tex.

Oil and gas fields are widely developed in the northern part of the Edwards Plateau, but only cattle ranches are found in the bare southern part.

Ancient oceans deposited the limestones that now cap the Edwards Plateau; streams planed off the surface of the flat-lying limestone layers and entrenched themselves in steep-walled valleys; and ground water dissolved the limestone and created the solution cavities that are the caves and sinks of the Edwards Plateau. Water has created this landscape.

## PLAINS BORDER SECTION

The Missouri Plateau, the Colorado Piedmont, the Pecos Valley, and the Edwards Plateau all were outlined by streams that flowed from the mountains. On the eastern border of the Great Plains, however, headward cutting by streams that have their source areas in the High Plains has dissected a large area, mainly in Kansas. This Plains Border Section comprises a number of east-trending river valleys—of the Republican, Solomon, Saline, Smoky Hill, Arkansas, Medicine Lodge, Cimarron, and North Canadian Rivers—and interstream divides, most of which are intricately dissected.

North of the Arkansas River, the east-flowing Republican, Solomon, Saline, and Smoky Hill Rivers have incised themselves a few hundred feet below the Tertiary High Plains surface and have developed systems of closely spaced tributary draws. The interstream divides are narrow, and the tributary heads nearly meet at the divides. This intricately dissected part of the Plains Border section is called the Smoky Hills. Some isolated buttes of Cretaceous rocks left in the upper valley of the Smoky Hill River are called the Monument Rocks. A large area of rounded boulders exposed by erosion south of the Solomon River, southwest of Minneapolis, Kans., is called "Rock City." These boulders originated as resistant nodules (concretions) within the Cretaceous rocks that contained them.

South of the Arkansas River is a broad, nearly flat upland sometimes referred to as the Great Bend Plains. The Medicine Lodge River has cut headward into the southeastern part of the Great Bend Plains and created a thoroughly dissected topography in Triassic red rocks that is locally called the Red Hills. In a few places, badlands have formed in the Red Hills.

Some large sinks or collapse depressions have formed because of solution of salt and gypsum at depth by ground water. Big and Little Basins, in Clark County in south-central Kansas, were formed in this way.

Sand dunes have accumulated in places, especially near stream valleys. Dunes are common, for example, along the north side of the North Canadian River.

Oil and gas fields are widely developed in the southeast part of the Plains Border section—in the Smoky Hills, the Great Bend Plains, and the Red Hills.

The Plains Border section, like the Missouri Plateau, the Colorado Piedmont, and the Pecos Valley, is primarily a product of stream dissection. The differences in the outstanding landforms of the section are mainly the result of differences in the hardness of the eroded rocks.

## EPILOGUE

The Great Plains, as we have seen, is many things. It contains thick layers of rock that formed in oceans, and younger layers of rocks deposited by streams. These rocks have been affected by earth movements and injected by hot molten rock, some of which reached the surface as volcanic rock. The rocks have been carved by streams, dissolved by ground water, partly covered by glaciers, and blown by winds. All of these agents have played important roles in determining the landscape and the landforms of the Great Plains. But the streams were the master agent. They formed the great depositional plain that was to become the Great Plains, and then began to destroy it—leaving only the High Plains to remind us of what it was. Those long miles we travel across the High Plains are a journey through history—geologic history.

## ACKNOWLEDGMENTS

This narrative history of geologic and biologic events in the Great Plains had its origin in a study intended to identify potential National Natural Landmarks in the Great Plains, commissioned by the National Park Service. William A. Cobban, G. Edward Lewis, and Reuben J. Ross of the U.S. Geological Survey were collaborators in that study, and some of their contributions to the history of life on the Great Plains have been incorporated into this narrative, which was undertaken at the urging of Wallace R. Hansen.

The photographic illustrations, other than those obtained from the film library of the U.S. Geological Survey, were provided by the interest and effort of my friends and colleagues of the Geological Survey—including C. R. Dunrud, V. L. Freeman, C. D. Miller, R. D. Miller, F. W. Osterwald, R. L. Parker, W. H. Raymond, III, Kenneth Shaver, and R. B. Taylor—and by Eugene Shearer, Intrasearch, Inc., Denver, Colo. Without their help this publication would not have been possible.

## SOME SOURCE REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geological Survey Professional Paper 174, 133 p.

Bluemle, J. P., 1977, The face of North Dakota—the geologic story: North Dakota Geological Survey Education Series 11, 73 p.

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of the Rocky Mountains: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327.

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-331.

Curtis, B. F., ed., 1975, Cenozoic history of the southern Rocky Mountains—Papers deriving from a symposium presented at the Rocky Mountain Section meeting of the Geological Society of America, Boulder, Colorado, 1973: Geological Society of America Memoir 144, 279 p.

Darton, N. H., 1905, Preliminary report on the geology and underground water resources of the central Great Plains: U.S. Geological Survey Professional Paper 32, 433 p.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geological Survey Professional Paper 262, 173 p.

Frye, J. C., and Leonard, A. B., 1965, Quaternary of the southern Great Plains, *in* Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States—A review volume for the 7th Congress of the International Association for Quaternary Research: Princeton University Press, p. 203–216.

Howard, A. D., 1958, Drainage evolution in northeastern Montana and northwestern North Dakota: Geological Society of America Bulletin, v. 69, no. 5, p. 575–588.

Johnson, R. B., 1961, Patterns and origin of radial dike swarms associated with West Spanish Peak and Dike Mountain, south-central Colorado: Geological Society of America Bulletin, v. 72, no. 4, p. 579–590.

Judson, S. S., Jr., 1950, Depressions of the northern portion of the southern High Plains of eastern New Mexico: Geological Society of America Bulletin, v. 61, no. 3, p. 253–274.

Keech, C. F., and Bentall, Ray, 1971, Dunes on the plains—The Sand Hills region of Nebraska: Nebraska University Conservation and Survey Division Resources Report 4, 18 p.

Lemke, R. W., Laird, W. M., Tipton, M. J., and Lindvall, R. M., 1965, Quaternary geology of northern Great Plains, *in* Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States—A review volume for the 7th Congress of the International Association for Quaternary Research: Princeton University Press, p. 15–27.

Mansfield, G. R., 1907, Glaciation in the Crazy Mountains of Montana: Geological Society of America Bulletin, v. 19, p. 558–567.

Pettyjohn, W. A., 1966, Eocene paleosol in the northern Great Plains, *in* Geological Survey research 1966: U.S. Geological Survey Professional Paper 550-C, p. C61–C65.

Robinson, C. S., 1956, Geology of Devils Tower National Monument, Wyoming: U.S. Geological Survey Bulletin 1021-I, p. 289–302.

Smith, H. T. U., 1965, Dune morphology and chronology in central and western Nebraska: Journal of Geology, v. 73, no. 4, p. 557–578.

Stormer, J. C., Jr., 1972, Ages and nature of volcanic activity on the southern High Plains, New Mexico and Colorado: Geological Society of America Bulletin, v. 83, no. 8, p. 2443–2448.

Strahler, A. N., and Strahler, A. H., 1978, Modern physical geography: New York, John Wiley & Sons, 502 p.

Thornbury, W. D., 1965, Regional geomorphology of the United States: New York, John Wiley, 609 p.

Wright, H. E., Jr., 1970, Vegetational history of the Central Plains, *in* Pleistocene and recent environments of the central Great Plains: Kansas University Department of Geology Special Publication 3, p. 157–172.

# INDEX

[Italic page numbers indicate major references]

☆ U S GOVERNMENT PRINTING OFFICE 1980—778-269

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

# STUDIES RELATED TO WILDERNESS



# MINERAL RESOURCES OF THE CRANBERRY WILDERNESS STUDY AREA, WEBSTER AND POCAHONTAS COUNTIES, WEST VIRGINIA

GEOLOGICAL SURVEY BULLETIN 1494

# Mineral Resources of the Cranberry Wilderness Study Area, Webster and Pocahontas Counties, West Virginia

*By* CHARLES R. MEISSNER, JR., *and* JOHN F. WINDOLPH, JR.,
U.S. GEOLOGICAL SURVEY
*and by* PETER C. MORY *and* DONALD K. HARRISON,
U.S. BUREAU *of* MINES

*With sections on*

## Peat Resources

*By* CORNELIA C. CAMERON *and* ANDREW E. GROSZ,
U.S. GEOLOGICAL SURVEY

## Oil and Gas Potential

*By* WILLIAM J. PERRY, JR., U.S. GEOLOGICAL SURVEY

## Geochemical Survey

*By* FRANK G. LESURE, U.S. GEOLOGICAL SURVEY

STUDIES RELATED TO WILDERNESS—WILDERNESS AREAS

GEOLOGICAL SURVEY BULLETIN 1494

*An evaluation of the mineral potential of the area*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1981

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

**Library of Congress Cataloging in Publication Data**

Main entry under title:
Mineral resources of the Cranberry Wilderness study area, Webster and Pocahontas Counties, West Virginia.

(Studies related to wilderness—wilderness areas)
(Geological Survey bulletin ; 1494)
Supersedes bulletin OF–78–142.
Bibliography: p.
Supt. of Docs. no.: I 19.3:1494–B
1. Mines and mineral resources—West Virginia—Cranberry Wilderness Study Area. I. Meissner, Charles R. II. Series. III. Series: United States. Geological Survey. Bulletin ; 1494.

QE75.B9 no. 1494 [TN24.W4] 557.3s 80–607145
[553'.09754'65]

For sale by Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

## STUDIES RELATED TO WILDERNESS STUDY AREAS

In accordance with the provisions of the Wilderness Act (Public Law 88–577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, and as specifically designated by PL93–622, January 3, 1975, the U.S. Geological Survey and U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. This report discusses the results of a mineral survey of national forest land in the Cranberry Study Area, West Virginia, that is being considered for wilderness designation (Public Law 93–622, January 3, 1975). The area studied is in the Monongahela National Forest in Webster and Pocahontas Counties.

## CONTENTS

## ILLUSTRATIONS

[Plates in pocket]

# TABLES

# CONVERSION FACTORS

| Metric unit | | Inch-Pound equivalent | |
|---|---|---|---|
| **Length** | | | |
| millimeter (mm) | = | 0.03937 | inch (in) |
| meter (m) | = | 3.28 | feet (ft) |
| kilometer (km) | = | .62 | mile (mi) |
| **Area** | | | |
| square meter ($m^2$) | = | 10.76 | square feet ($ft^2$) |
| square kilometer ($km^2$) | = | .386 | square mile ($mi^2$) |
| hectare (ha) | = | 2.47 | acres |
| **Volume** | | | |
| cubic centimeter ($cm^3$) | = | 0.061 | cubic inch ($in^3$) |
| liter (L) | = | 61.03 | cubic inches |
| cubic meter ($m^3$) | = | 35.31 | cubic feet ($ft^3$) |
| cubic meter | = | .00081 | acre-foot (acre-ft) |
| cubic hectometer ($hm^3$) | = | 810.7 | acre-feet |
| liter | = | 2.113 | pints (pt) |
| liter | = | 1.06 | quarts (qt) |
| liter | = | .26 | gallon (gal) |
| cubic meter | = | .00026 | million gallons (Mgal or $10^6$ gal) |
| cubic meter | = | 6.290 | barrels (bbl) (1 bbl=42 gal) |
| **Weight** | | | |
| gram (g) | = | 0.035 | ounce, avoirdupois (oz avdp) |
| gram | = | .0022 | pound, avoirdupois (lb avdp) |
| metric tons (t) | = | 1.102 | tons, short (2,000 lb) |
| metric tons | = | 0.9842 | ton, long (2,240 lb) |
| **Specific combinations** | | | |
| kilogram per square centimeter ($kg/cm^2$) | = | 0.96 | atmosphere (atm) |
| kilogram per square centimeter | = | .98 | bar (0.9869 atm) |
| cubic meter per second ($m^3/s$) | = | 35.3 | cubic feet per second ($ft^3/s$) |

| Metric unit | | Inch-Pound equivalent | |
|---|---|---|---|
| **Specific combinations—Continued** | | | |
| liter per second (L/s) | = | .0353 | cubic foot per second |
| cubic meter per second per square kilometer [$(m^3/s)/km^2$] | = | 91.47 | cubic feet per second per square mile [$(ft^3/s)/mi^2$] |
| meter per day (m/d) | = | 3.28 | feet per day (hydraulic conductivity) (ft/d) |
| meter per kilometer (m/km) | = | 5.28 | feet per mile (ft/mi) |
| kilometer per hour (km/h) | = | .9113 | foot per second (ft/s) |
| meter per second (m/s) | = | 3.28 | feet per second |
| meter squared per day ($m^2/d$) | = | 10.764 | feet squared per day ($ft^2/d$) (transmissivity) |
| cubic meter per second ($m^3/s$) | = | 22.826 | million gallons per day (Mgal/d) |
| cubic meter per minute ($m^3/min$) | = | 264.2 | gallons per minute (gal/min) |
| liter per second (L/s) | = | 15.85 | gallons per minute |
| liter per second per meter [(L/s)/m] | = | 4.83 | gallons per minute per foot [(gal/min)/ft] |
| kilometer per hour (km/h) | = | .62 | mile per hour (mi/h) |
| meter per second (m/s) | = | 2.237 | miles per hour |
| gram per cubic centimeter ($g/cm^3$) | = | 62.43 | pounds per cubic foot ($lb/ft^3$) |
| gram per square centimeter ($g/cm^2$) | = | 2.048 | pounds per square foot ($lb/ft^2$) |
| gram per square centimeter | = | .0142 | pound per square inch ($lb/in^2$) |
| **Temperature** | | | |
| degree Celsius (°C) | = | 1.8 | degrees Fahrenheit (°F) |
| degrees Celsius (temperature) | = | [(1.8×°C)+32] | degrees Fahrenheit |

# MINERAL RESOURCES OF THE CRANBERRY WILDERNESS STUDY AREA, WEBSTER AND POCAHONTAS COUNTIES, WEST VIRGINIA

By CHARLES R. MEISSNER, JR., and JOHN F. WINDOLPH, JR.,
U.S. GEOLOGICAL SURVEY
*and*
PETER C. MORY and DONALD K. HARRISON,
U.S. BUREAU OF MINES

## SUMMARY

The Cranberry Wilderness Study Area comprises 14,702 ha in the Monongahela National Forest, Webster and Pocahontas Counties, east-central West Virginia. The area is in the Yew Mountains of the Appalachian Plateaus and is at the eastern edge of the central Appalachian coal fields. Cranberry Glades, a peatland of botanical interest, lies at the southern end of the study area. All surface rights in the area are held by the U.S. Forest Service; nearly 90 percent of the mineral rights are privately owned or subordinate to the surface rights.

Sedimentary rocks of Mississippian and Pennsylvanian age are exposed in the area and have a gentle regional dip to the northwest. The oldest rocks are of Late Mississippian age and are composed predominantly of red shale and siltstone, and sandstone, containing a few lenticular coal beds. They crop out in the southern part of the area and along the deeper river valleys to the north. Overlying Lower Pennsylvanian rocks of the Pocahontas and New River Formations have a higher ratio of sandstone to shale than the Mississippian units and contain economically important coal beds. The Pennsylvanian rocks crop out in all but the southernmost part of the area, where they have been removed by erosion.

Bituminous coal of coking quality is the most economically important mineral resource in the Cranberry Wilderness Study Area. Estimated resources in beds 35 cm thick or more are about 100 million metric tons in nine coal beds. Most measured-indicated coal, 70 cm thick or more (reserve base), is in a 7-km-wide east-west trending belt extending across the center of the study area. The estimated reserve base is 34,179 thousand metric tons. Estimated reserves in seven of the coal beds total 16,830 thousand metric tons and are recoverable by underground mining methods.

Other mineral resources, all of which have a low potential for development in the study area, include peat, shale, and clay suitable for building brick and lightweight aggregate, sandstone for low-quality glass sand, and sandstone suitable for construction material.

Evidence derived from drilling indicates little possibility for oil and gas in the study area. No evidence of economic metallic deposits was found during this investigation.

## INTRODUCTION

Cranberry Wilderness Study Area comprises 14,702 ha in the Monongahela National Forest, east-central West Virginia. The area is in parts of Webster and Pocahontas Counties, about 13 km west of Marlinton, W. Va. (fig. 1). The study area can be reached by several improved roads. Access to the northeastern corner is by State Highway 17 to U.S. Forest Route 86. Route 86, a graded gravel road, parallels the Williams River and forms the northern and northeastern boundary of the area (fig. 2). State Highway 39 abuts the southern end of the area and State Highway 150 follows the mountain crest along the southern and eastern boundaries of the study area. U.S. Forest Route 102, which extends from State Highway 39, parallels the Cranberry River and provides access for restricted vehicular traffic along the southwestern boundary. U.S. Forest Service roads, old logging railroad grades, and a few primitive trails provide access by foot or horseback to the interior. All motor-vehicle traffic or motorized equipment is prohibited inside the Cranberry Wilderness Study Area.

The area, dominated topographically by the Yew Mountains of the Appalachian Plateaus, is at the eastern edge of the central Appalachian coal fields. Elevations range from about 730 m (2,080 ft) above sea level in the Middle Fork valley to 1,390 m (4,559 ft) above sea level on Black Mountain. Principal streams are the Williams, Middle Fork of the Williams, Cranberry, and the North Fork of the Cranberry River.

The lower mountain slopes are covered by a variety of second growth northern hardwood trees including yellow birch, maple, black ash, and oak. Large groves of red spruce dominate the mountain crests and are underlain by a thick carpet of moss. The area was heavily logged between 1910 and 1926, and little virgin forest remains. Small selected tracts totaling 245 ha were also logged in the early 1950's.

A major tourist attraction is the Cranberry Glades Botanical Area, which covers about 304 ha at the southern end of the study area. These glades are likened to the tundra country of Alaska, containing peat, reindeer moss, sedges, high bush cranberry (vibernum) and other shrubs, as well as birds and animals native to more northern areas of the United States.

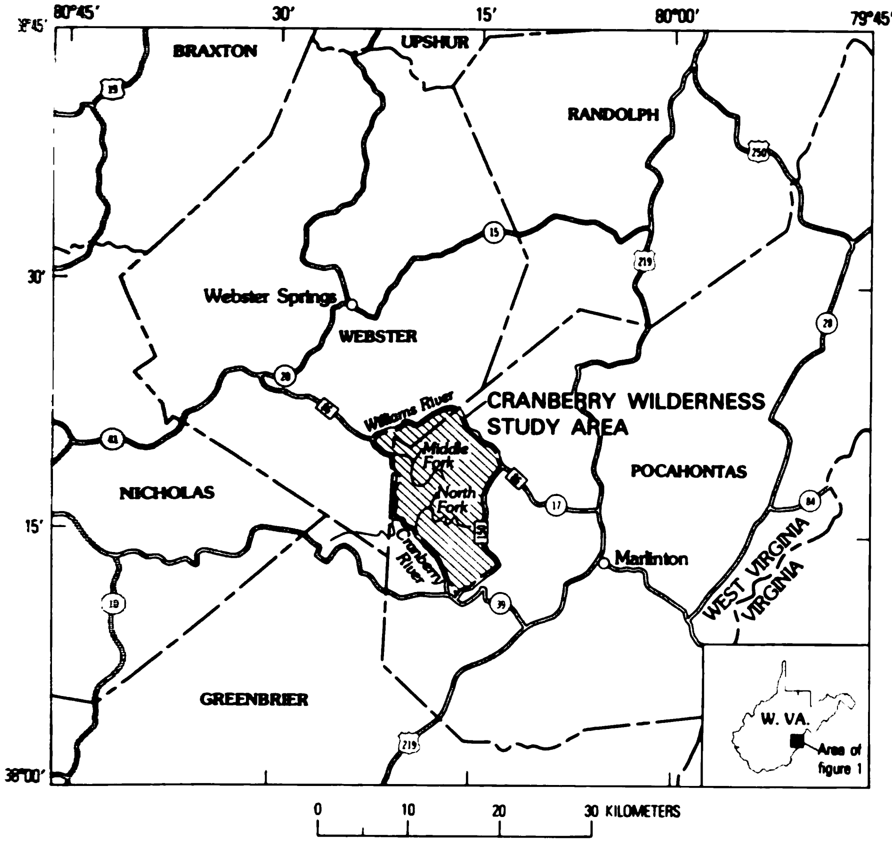



**FIGURE 1.**—Index map showing the location of the Cranberry Wilderness Study Area in east-central West Virginia.

## SURFACE AND MINERAL OWNERSHIP

All surface-land rights were purchased by the Federal Government in the 1930's under the authority of the Weeks Act of 1911 and are held by the U.S. Forest Service. Nearly 86 percent of the mineral rights are owned by Mid Allegheny Corp. The remainder of the mineral rights either are owned outright (10 percent) by the U.S. Forest Service or are subordinate (4 percent) to the surface-land rights (fig. 3). The owner of the mineral rights reserved the privilege to cross the subordinated area by underground openings or mine headings.

FIGURE 2.—View of Williams River, looking east along U.S. Forest Route 86. The cliff at the roadside is in the Princeton(?) Sandstone.

## PREVIOUS INVESTIGATIONS

Descriptions of the geology and coal resources of the Cranberry Wilderness Study Area may be found in the West Virginia Geological Survey reports on Webster County by Reger, Tucker, and Buchanan (1920), and on Pocahontas County by Price and Reger (1929). Both reports include a county geologic map at a scale of 1:62,500.

A generalized informative report on coal and coal mining in West Virginia and regional characteristics of the coal in the study area was prepared by Barlow (1974).

An unpublished report prepared by the U.S. Forest Service (1975) describes the geology and evaluates the coal resources of three areas within the Monongahela National Forest. These areas are the Cranberry Back Country and its environs, the Shavers Fork Area, and the Otter Creek Area. The Cranberry Wilderness Study Area covers about one-fourth of the Cranberry Back Country and its environs. Estimates of coal reserves, 70 cm thick or more, were made for the larger Cranberry Back Country by

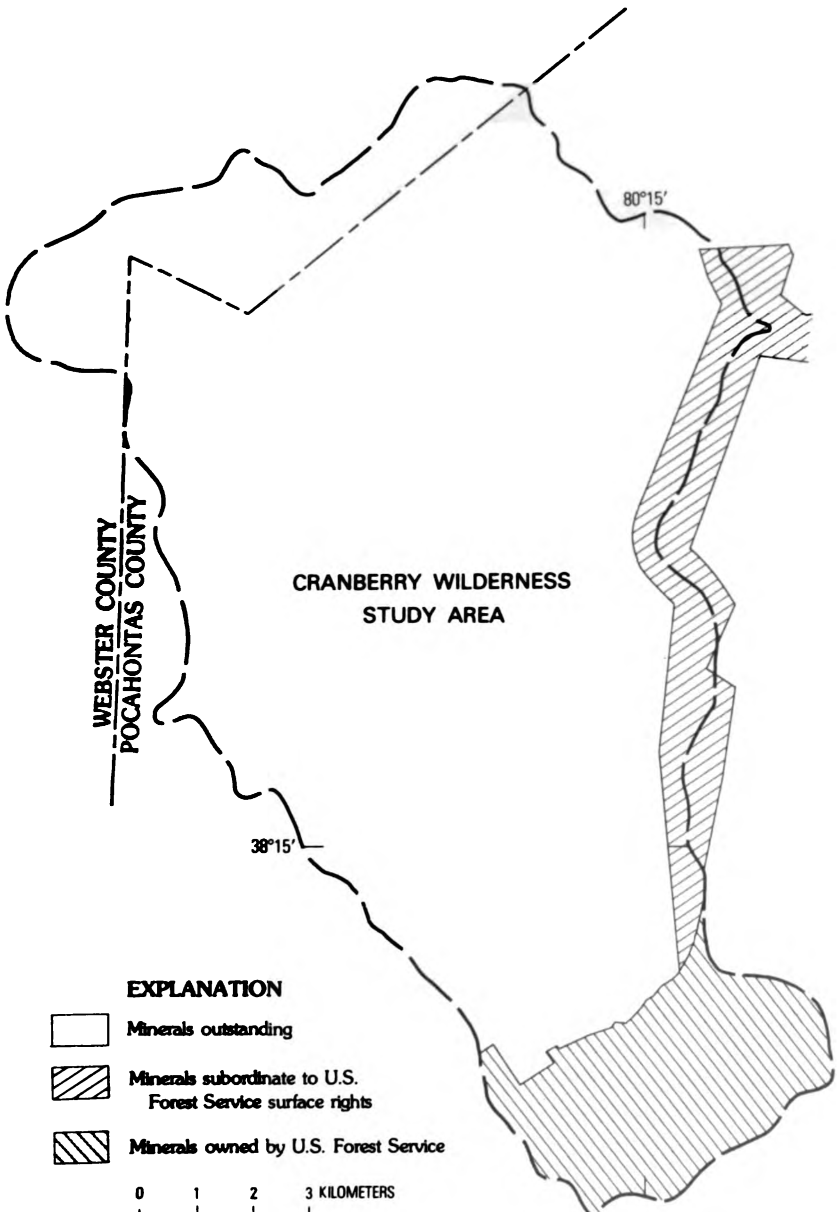



FIGURE 3.—Status of mineral ownership, Cranberry Wilderness Study Area.

the Forest Service; tonnage estimates currently made for the smaller wilderness study area could not be directly compared with those of larger areas.

Several reports have been published concerning the peat deposits of the Cranberry Glades at the south end of the study area (Darlington, 1943, Core, 1955, and Cameron, 1970, 1972).

## PRESENT INVESTIGATIONS

U.S. Geological Survey fieldwork and collection of data were done by C. R. Meissner, Jr., and J. F. Windolph, Jr., during April 1977. This work consisted of reconnaissance geologic mapping, measuring sections, and describing diamond drill cores. Coal beds were mapped and correlated by relating them to mappable resistant sandstone units throughout the study area. Field mapping within the study area was supplemented by lithologic data obtained from more than 60 coal company drill-core logs, augmented by 20 U.S. Forest Service drill logs, and maps of inactive mines. Geochemical survey sampling was done by F. G. Lesure, C. E. Brown, A. E. Grosz, and J. W. Whitlow during 6 days in April 1977. Stream sediment and rock samples were analyzed in the U.S. Geological Survey laboratories, Denver, Colo. W. J. Perry, Jr., examined oil and gas records and studied available publications for information on oil and gas potential. C. C. Cameron and A. E. Grosz evaluated peat resources during a 1-week field study in May 1977.

U.S. Bureau of Mines field reconnaissance was conducted by P. C. Mory and D. K. Harrison; they were assisted by M. L. Dunn, Jr., and P. T. Behum in the spring and summer of 1977. Prospects, mines, exposures, and drill sites in and near the area were examined with primary emphasis on evaluating coal beds. Fifty-four coal-prospect trenches and adits in the area were examined and nine localities were sampled. Mine maps from the Bureau's Eastern Field Operations Center Mine Map Repository, Pittsburgh, Pa., were examined to determine the extent of coal mining in or near the study area, and to aid in coal-bed correlation. Thirty-one rock samples of sandstone, underclay, and shale, and, six peat samples from four bogs in Cranberry Glades were collected for analysis.

Coal and peat samples were tested by the Department of Energy, Division of Solid Fuel Mining and Preparation, Coal Analysis (formerly the U.S. Bureau of Mines, Coal Preparation and Analysis Group), Pittsburgh, Pa. The Bureau's Reno Metallurgy Research Center, Reno, Nev., conducted spectrographic, chemical, atomic absorption, and radiometric analyses on rock and coal-ash samples. Ceramic and lightweight aggregate evaluations of shale and clay samples were made by the U.S. Bureau of Mines, Tuscaloosa Metallurgy Research Center, Tuscaloosa, Ala.

### ACKNOWLEDGMENTS

We are grateful to David T. Morrison, executive vice president, and Forrest Jones, geologist, of Mid Allegheny Corp., Summerville, W. Va., for supplying copies of drill logs and coal washability data. The West Virginia Geological Survey, Oil and Gas Division, made available oil and gas drill-hole information. Appreciation is extended to U.S. Forest Service personnel in the Eastern Region Office, Milwaukee, Wis.; Roger Johnson and Thomas R. Manley, Monongahela National Forest Headquarters Office, Elkins, W. Va.; and Ronald E. Scott, Gauley Ranger Station, Richwood, W. Va., for providing surface- and mineral-ownership information, drill-hole information, and access privileges to the study area.

## GEOLOGY

### GEOLOGIC SETTING

The Cranberry Wilderness Study Area is west of the northeast-trending Deer Creek anticline in the erosional Yew Mountains of the Appalachian Plateaus. It is underlain by gently northwest dipping sedimentary rocks of Pennsylvanian and Mississippian age (pl. 1, geologic map and cross section). The oldest exposed rocks of Late Mississippian age crop out in the lower slopes of the more deeply incised valleys and underlie flat lowlands along the headwaters of the Cranberry River where the peat-bearing Cranberry Glades are found. Overlying Pennsylvanian rocks cap the higher slopes and ridges in the central and northern part of the area. Surficial colluvial deposits mantle much of the mountainsides and, with alluvium, are found in the valley floors. Bedrock exposures are limited to a few localities along major stream beds and ridge crests.

### MISSISSIPPIAN ROCKS

Upper Mississippian sedimentary rocks in or near the study area include, from oldest to youngest, the Greenbrier Limestone, Bluefield Formation, Hinton Formation, Princeton(?) Sandstone, and Bluestone Formation (pl. 1). Total thickness of these rocks is about 770 m. They consist of sandstone, siltstone, shale, limestone, minor amounts of underclay, and two or more lenticular beds of impure coal. These rocks represent deltaic near-shore, swamp, intertidal, and marine deposits.

### GREENBRIER LIMESTONE

Outcrops of Greenbrier Limestone of Late Mississippian age just south of the study area were selected as the starting point for examining the stratigraphic sequence, because of the easy recognition and widespread occurrence of the formation. An oil and gas test well near the west-central edge of the study area penetrated a total thickness of 138 m of Greenbrier. The upper 55 m of the formation are well exposed 1.5 km south of the study area on State Route 39. The Taggard Red(?) Member, a castellated grayish-red shaly siltstone, is exposed about 10 m above the base of the outcrop, and is considered a key bed for correlation (pl. 1, stratigraphic column). The Greenbrier consists of medium- to dark-gray, very finely to coarsely crystalline limestone, containing oolites, calcareous pellets, fossil fragments, quartz grains, and chert nodules. Interbeds of greenish-gray to grayish-red shale and siltstone are dominant near the top. The limestone units are mostly thick bedded to massive and contain some crossbedded detrital sandy zones. The contact between the Greenbrier and the overlying Bluefield Formation is transitional from mostly limestone in the Greenbrier to calcareous shale and argillaceous limestone in the Bluefield.

### BLUEFIELD FORMATION

The Bluefield is the oldest formation exposed in the study area. The upper part of the formation, approximately 50 m thick, crops out on the south side of Cranberry Glades. The underlying part of the formation, approximately 267 m thick, was examined where it is exposed above the Greenbrier Limestone along State Route 39 just south of the area. The formation consists of partly calcareous grayish-red and greenish-gray shale, and interbeds of lenticular sandstone and siltstone. Dark-gray to black clayey limestone is interbedded with shale at the base of the formation. Root zones overlain by thin, bony lenticular coal beds occur in the lower part of the unit. The formation is conformably overlain by the Stony Gap(?) Sandstone Member of the Hinton Formation.

### HINTON FORMATION

The Hinton Formation crops out in the southern part of the study area along the lower slopes of the mountains and in adjacent valleys. It is composed of grayish-red shale and a few thin beds of gray to grayish-red sandstone and conglomerate lenses containing rounded to angular limestone pebbles. Thickness of the Hinton Formation is about 155 m. The Stoney Gap(?) Sandstone Member at the base of the formation is exposed in the lower slopes of the mountains surrounding Cranberry Glades. There, it consists of light-greenish-gray thin-bedded sandstone that is distinguishable from the sandstone of the underlying Bluefield Formation by less carbonaceous material and dark minerals. The contact between the Bluefield and the overlying Princeton(?) Sandstone is irregular because of channelling.

### PRINCETON(?) SANDSTONE

The Princeton(?) Sandstone is exposed in the upper slopes of the mountains at the south part of the study area. It descends gradually northwestward because of the regional dip to lower elevations along the mountainsides, and locally forms resistant outcrops in the creek and river beds of the central and northern areas (pl. 1, geologic map). It dips below the stream valleys along the western side of the area. The Princeton(?) ranges in thickness from 12 to 24 m and is composed of medium-gray to light-greenish-gray thick-bedded to massive lenses of sandstone and conglomerate, containing rounded quartz and limestone pebbles as much as 2 cm long (pl. 1, stratigraphic column). The formation is resistant to weathering and forms ledges or prominent benches. The Princeton(?) Sandstone appears to be conformably overlain by the Pride(?) Shale Member of the Bluestone Formation.

### BLUESTONE FORMATION

The Bluestone Formation ranges in thickness from less than 60 m to 100 m or more and consists, in ascending stratigraphic order, of the Pride(?) Shale and Glady Fork(?) Sandstone Members, and one unnamed upper member. The formation is exposed at the crests of the mountains in the south part of the area but, because of regional dip, descends gradually below the valley bottoms in the western and northern part (pl. 1, geologic map).

The Pride(?) Shale Member occupies most of the lower half of the formation and has an average thickness of about 40 m. It consists of medium- to dark-gray and some grayish-red and greenish-gray shale, which locally grades to silty shale. The shale is evenly bedded and contains marine pelecypod and ostracode fossils. A lenticular impure coal bed, locally as much as 61 cm thick, is the uppermost unit of the member and is directly overlain by the Glady Fork(?) Sandstone Member.

The Glady Fork(?) Sandstone Member crops out near the south end of State Highway 150 and near the junction of the Cranberry River and the North Fork where it paves the streambed. This member, near the middle of the Bluestone Formation, has an average thickness of 10 m and probably underlies most of the area. It consists of thick-bedded to massive lenses of sandstone and conglomerate containing rounded quartz and limestone pebbles.

The upper member of the formation averages 45 m in thickness and is composed of grayish-red shale and sandstone and a few lenticular conglomerate beds. The uppermost part of the member intertongues and grades laterally into the lower beds of the Pocahontas Formation of Pennsylvanian age. Where intertonguing has occurred, both formations are classified as Pennsylvanian in age. However, in those localities where the Pocahontas Formation has been removed by erosion, an unconformable contact separates the Bluestone from the New River Formation of Pennsylvanian age.

## PENNSYLVANIAN ROCKS

Lower Pennsylvanian coal-bearing rocks of the Pocahontas and New River Formation crop out in all but the southernmost part of the study area. Where these rocks are present, they form the upper parts of the mountains in the south and, as a result of the northwesterly regional dip, constitute most of the exposed rocks in the mountains of the central and northern parts of the area. The Lower Pennsylvanian rocks are mostly of continental origin, consist of sandstone, shale, underclay, siltstone, and conglomerate, and contain six major coal beds as well as several thinner and less extensive beds of economic importance. The thickness of the two formations is about 326 m.

### POCAHONTAS FORMATION

The Pocahontas Formation, a relatively thin unit in the area that has a maximum thickness of about 21 m, is economically significant because it contains the Pocahontas No. 3(?) coal bed. In the southern part of the area, exposures occur high in the mountains; northwestward, they are much lower, and the formation is exposed along the sides of the deeper stream valleys. This formation, previously unknown in the study area, has been extended 25 km northeastward of previously mapped occurrences and pinches out along an east-west trend in the northern part of the study area. The formation is composed of gray to very dark gray shale and siltstone, coal, and underclay. Abundant plant material, including leaf pinules of the *Neuropteris Pocahontas* (W. H. Gillespie, oral comm., 1978), was found in the roof rock above the Pocahontas No. 3(?) coal bed.

### NEW RIVER FORMATION

Most rocks exposed in the study area are assigned to the New River Formation, which has a total thickness of more than 300 m. Several important coal beds occur in this formation, including the Sewell, Little Raleigh(?), Beckley(?), and Fire Creek(?). Four sandstone and conglomerate members were mapped to aid correlation of the coal beds: (1) basal sandstone and conglomerate probably correlative with the Pineville Sandstone Member; (2) sandstone and conglomerate below the Little Raleigh(?) coal bed; (3) sandstone and conglomerate above the Sewell coal bed; and (4) ortho-quartzite above the Hughes Ferry(?) coal bed.

The basal sandstone and conglomerate member occurs in all but the northern quarter of the study area where it pinches out (pl. 1, geologic map). The member is light gray, and in many places contains white rounded quartz pebbles as much as 3 cm in diameter. It forms a bench or ledge and has a maximum thickness of about 49 m in the central part of the study area.

The sandstone and conglomerate below the Little Raleigh(?) coal bed is light gray, locally contains pebbles, is thick to very thick bedded and forms resistant benches. Maximum thickness is about 36 m, but the unit grades laterally into shale northwestward and pinches out in the northwestern corner of the study area. Erosional fragments from the unit commonly accumulate as boulder colluvium at the base of slopes.

The sandstone and conglomerate unit above the Sewell coal bed crops out extensively in the mountains in the northern part of the study area. It underlies all the highest knobs in the central part and has been eroded away in the southern part of the study area. Maximum thickness is about 30 m, and the sandstone locally contains two or more lenticular shale beds as much as 4 m thick. The unit is commonly conglomeratic and contains lenses of quartz pebbles as much as 1 cm in diameter. It forms resistant ledges, cliffs, and benches, which weather into boulders and rock debris.

The ortho-quartzite unit is preserved only on the crest of the mountain west of Laurelly Branch at the western border of the study area. It contains 80–90 percent quartz sand at the top and becomes less quartzose toward the base. This unit may be correlative with the basal part of the Nuttall Sandstone Member that elsewhere is the uppermost member of the New River Formation.

## QUATERNARY DEPOSITS

Colluvim mantles most mountainsides and covers all but a few good bed-rock exposures. The colluvium deposits were not mapped, because time was not available to delineate their boundaries. Most of the stream valleys are strewn with sandstone boulders, but deposits of sand, silt, mud, and some coarse rock material are present in the headwaters of Cranberry River, of the North Fork of the Cranberry, and along much of the Middle Fork of the Williams River (pl. 1, geologic map). A large landslide was mapped in the Bluestone Formation on the east side of the Middle Fork, north of its junction with Laurelly Branch. Other less extensive landslides have occurred throughout the study area but have not been mapped.

The peat bogs of the Cranberry Glades in the south end of the study area are a unique feature because they contain fauna and flora usually found much farther north. Their origin and characteristics are described in the chapter on "Mineral Resources."

## STRUCTURE

The structure contours for plate 2 were drawn on the base of the Beckley(?) coal bed in the study area. In the southern part of the area where the Beckley(?) is absent, elevations were projected by an average interval from points on older or younger coal beds. The resulting structure map, which generally reflects the structure for the area, reveals a northwesterly dipping homocline. The average strike is N. 38° E., and the dip ranges from 1° to 4° and averages slightly less than 2° NW. This average dip results in a northwestward drop in the elevation of the Beckley(?) coal bed of 185 feet per mile (35m/km). The strike of cleats in the coal beds ranges from N. 35° W. to N. 10° W. for the face cleat and N. 35° E. to N. 60° E. for the butt cleat. The dips range from 82° to vertical wavering from northeast to southwest for the face cleat and northwest to southeast for the butt cleat.

## MINERAL RESOURCES

### SETTING

Potential mineral resources in the Cranberry Wilderness Study Area consist of coal, peat, shale and clay, high-silica sandstone, and stone. The area has a low potential for gas and practically no potential for oil. A geochemical survey indicates no potential for metallic minerals.

Coal has been prospected extensively and constitutes the most economically important mineral resource in the study area. The locations of at least 65 drill holes, 54 prospect trenches, and 10 adits shown on figure 4 are known in the study area.

Several surface and underground coal mines that are currently inactive have operated within 2 km of the northern border of the area. There is no record of commercial production within the study area, although several small openings may have furnished coal for locomotives used in logging operations.

Minerals, other than coal, have not been mined in or near the study area. However, rock units similar to those within the study area have the potential for economic mineral production in other parts of the State. McCue and others (1948) reported that shales and clays suitable for brick and tile are abundant throughout the State. Seventeen West Virginia clay beds are possible sources of alumina (Tallon and Hunter, 1959). In addition, high-silica sandstones have been identified at various localities in the State in rocks of Early Pennsylvanian and Mississippian age (Arkle and Hunter, 1957, p. 36). Uneconomic quarrying of building stone has been reported in southeastern Webster County (Reger and others, 1920).

### COAL

Coal beds tentatively identified within the study area are the Pocahontas No. 3(?), Pocahontas No. 3(?) rider, Little Fire Creek(?), Fire Creek(?), Beckley(?), Little Raleigh(?), Little Raleigh(?) rider, Sewell, and Hughes Ferry(?).

The names assigned to these coal beds do not agree with those assigned in earlier reports or with those in common local usage. All names were assigned after the Sewell coal bed was successfully correlated into the area from known Sewell outcrops and mines west and south of the area. All the identified beds except the Sewell and Hughes Ferry(?) contain coal of economically minable thickness. Areally, the most extensive beds are the

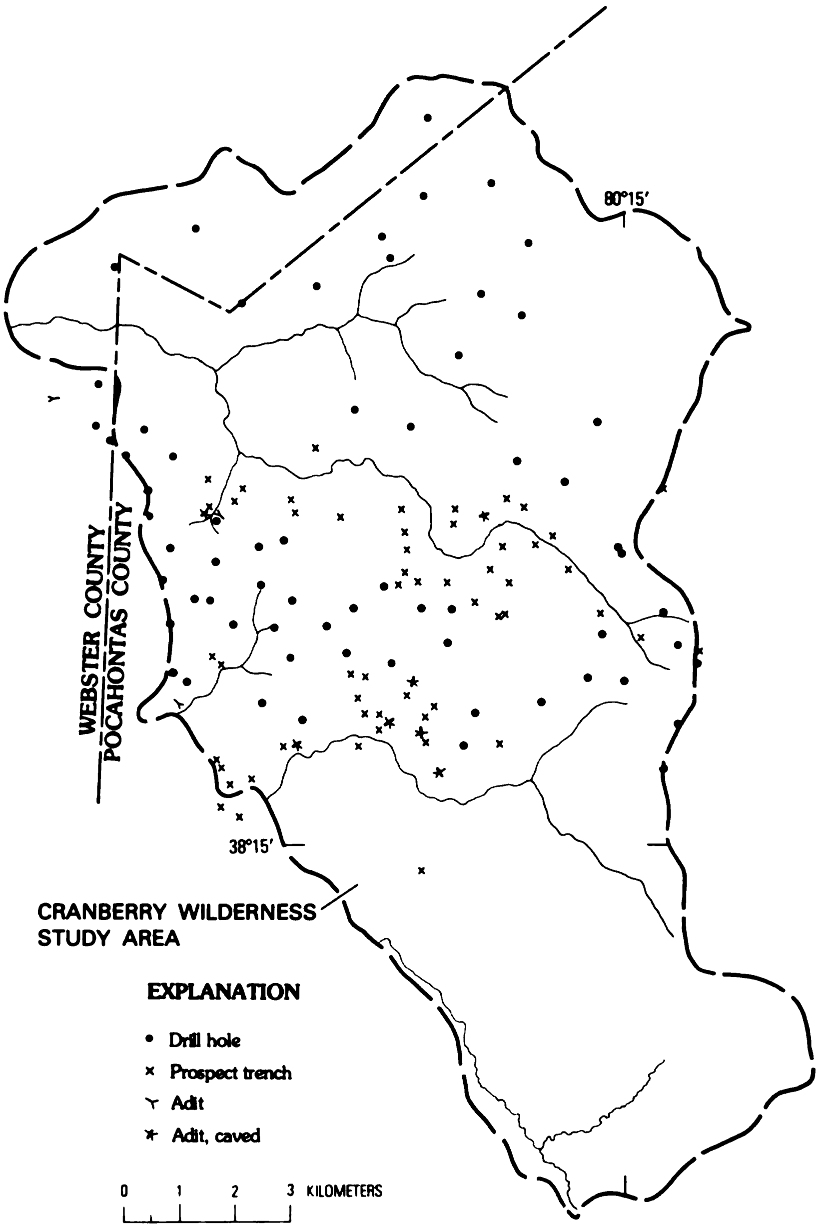



FIGURE 4.—Extent of coal exploration, Cranberry Wilderness Study Area.

Pocahontas No. 3(?), Fire Creek(?), Beckley(?), Little Raleigh(?), and Sewell.

Estimated coal resources are about 100 million metric tons (pl. 3). The reserve base (demonstrated reserve base) is

TABLE 1.—*Summary of estimated coal reserves, Cranberry Wilderness Study Area, W. Va.*

[By P. C. Mory and D. K. Harrison, U.S. Bureau of Mines, Nov. 15, 1977]

| Coal bed | Hectares of coal 70 cm or more thick | Reserve base (thousand metric tons) | | | Reserves [1] (thousand metric tons) |
|---|---|---|---|---|---|
| | | Measured | Indicated | Total | |
| Little Raleigh(?) rider | 102 | 470 | 604 | 1,074 | 537 |
| Little Raleigh(?) | 724 | 6,631 | 1,818 | 8,449 | 4,225 |
| Beckley(?) | 641 | 4,648 | 2,199 | 6,847 | 3,424 |
| Fire Creek(?) | 174 | 1,639 | 440 | 2,079 | 1,040 |
| Little Fire Creek(?) | 150 | 875 | 744 | 1,619 | 810 |
| Pocahontas No. 3(?) rider | 42 | 375 | 150 | 525 | 263 |
| Pocahontas No. 3(?) | 820 | 5,229 | 8,357 | 13,586 | [2] 6,531 |
| Total tonnages | | 19,867 | 14,312 | 34,179 | 16,830 |

[1] Based on 50 percent recovery factor.
[2] Excludes isolated economically unrecoverable parts of coal bed.

34,179,000 metric tons and reserves are 16,830,000 metric tons (table 1). Coal resources underlie most of the northern three-quarters of the study area (fig. 5); the reserve base underlies the central part (fig. 6).

Coal resources include all coal beds 35 cm thick or more, whereas reserves are limited, as classified herein, to coal 70 cm thick or more in the measured and indicated categories explained in "Procedure." The reserves would be recoverable by underground mining methods. Adverse environmental impacts could be minimized by use of appropriate mining techniques. All surface disturbance caused by mining would be temporary and limited to small areas. The drainage area and the water table of the Cranberry Glades are isolated from the coal reserve area. The bogs are upstream from the coal reserves, are updip on older rocks that are not related to aquifers of the coal-bearing areas, and would, therefore, not be harmed by mining.

## PROCEDURE

Coal bed investigations and evaluations consisted of surface geologic mapping, subsurface correlation of drill-core logs, and collection and analysis of coal samples. Correlation and identification of coal beds and rock formations in the core holes were made by the U.S. Geological Survey. Surface mapping included locating all prospect trenches and adits on the geologic map and determining which coal beds the trenches and adits were testing. U.S. Bureau of Mines personnel located 54 prospect trenches and adits within the study area; 32 were reopened and examined. Six inactive mines and 2 adits outside the area were also examined.

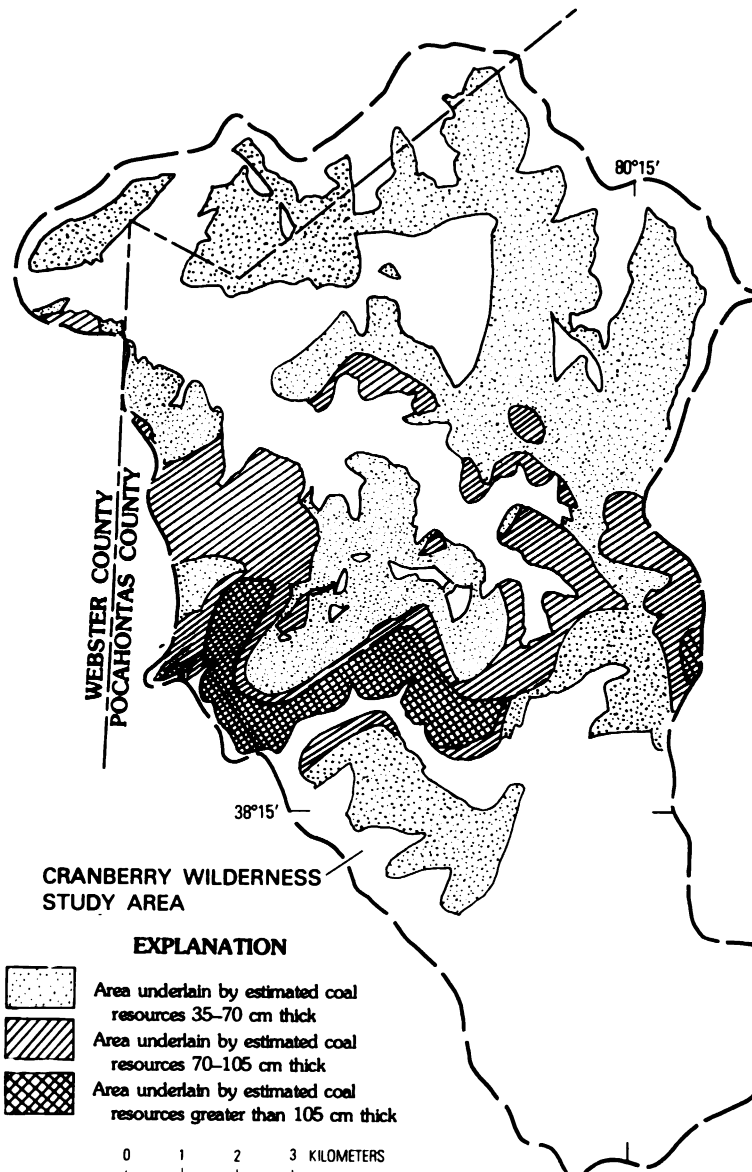



FIGURE 5.—Coal resource distribution of all beds in the Cranberry Wilderness Study Area.

A "bed map" prepared for each of the coal beds by the U.S. Geological Survey (pl. 3) shows: (1) coal thickness contours for 35, 70, and 105 cm, and (2) the coal bed outcrop and distribution.


FIGURE 6.—Composite reserve base area of all coal beds.

The estimate of coal resources is divided into categories based on reliability of data (distance from a point of measurement) and thickness of a coal bed (exclusive of partings and bony coal) for each coal bed. The reliability categories are measured, indicated, and inferred. Measured coal is projected to extend 0.4 km from a point of surface or subsurface measurement; indicated coal extends in a belt from more than 0.4 to 1.2 km from a measurement point; and inferred coal is projected to extend in a belt that is more than 1.2 to 4.8 km from a measurement point (U.S. Bureau of Mines and U.S. Geological Survey, 1976). Each area of coal categorized as measured, indicated, and inferred is divided into subareas that are based on coal thicknesses of 35, 70, and 105 cm or greater. No resources were estimated for coal beds less than 35 cm thick.

The reserve base is an estimate of the quantity of coal 70 cm thick or more in those parts of beds that are assigned to the measured and indicated reliability categories. Coal beds of this thickness generally are considered recoverable by underground-mining methods. Coal that could be strip mined is included in the reserve base and was not calculated separately. A 50-percent recovery factor was used to estimate the reserves (the quantity of recoverable coal) from the reserve base. Reserve base maps were modified from the individual bed maps. Past mining is negligible in the study area.

Analyses (table 2) indicate that coal in the study area can be tentatively ranked as medium-volatile to high-volatile A bituminous. All samples are low in sulfur and most are low in ash. Most of the raw coal is of premium-grade coking-coal quality and contains not more than 1.0 percent sulfur and 8.0 percent ash. Washability tests (table 3) performed on drill-core samples and on bulk samples from three adits indicate that any coal not of premium quality can be cleaned to reduce sulfur and ash content.

Spectrographic analyses of coal ash for 39 elements and radiometric determination of $U_3O_8$ (table 4) indicate no abnormal concentrations.

Trace-element contents of coal ash from the study area compare favorably with the averages for trace elements in coal ash of West Virginia as reported by Abernethy and others (1969) and Swanson and others (1976).

### POCAHONTAS NO. 3(?) COAL BED

The Pocahontas No. 3(?) coal bed (fig. 7) ranges in thickness from 0 to 170 cm. In most places the bed is free of partings, but locally may have several bony coal layers 2 to 5 cm thick. This coal bed crops out and is thickest along the north bank of the North Fork near its junction with the Cranberry River. Resources

FIGURE 7.—Pocahontas No. 3(?) coal bed, sample locality WVC-623. Coal extends from base of shovel to about 30 cm above top of handle.

in this bed underlie the central part of the study area, although two small blocks were identified north of this central band (pl. 3). One block is northeast of the headwaters of the Middle Fork of the Williams River; the other underlies a high ridge west of

TABLE 2.—*Analyses of coal, Cranberry*

[Analyses by Department of Energy, Division of Solid Fuel Mining and Preparation, Coal Pa. All samples are of weathered coal and were collected from adits, prospect trenches, or effects of weathering on analytical results]

| Sample number | Coalbed | Sample interval (centi- meters) | Specific gravity | Condition of sample 1/ | Proximate (percent) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Moisture | Volatile matter | Fixed carbon |
| | | | | AR | 6.3 | 27.0 | 60.9 |
| WVC-626 | Little | 106.7 | 1.37 | MF | -- | 28.9 | 64.9 |
| | Raleigh (?) | | | MAF | -- | 30.8 | 69.2 |
| | | | | AR | 6.7 | 27.9 | 60.3 |
| WVC-627 | do. | 105.4 | 1.36 | MF | -- | 29.9 | 64.6 |
| | | | | MAF | -- | 31.6 | 68.4 |
| | | | | AR | 3.1 | 29.6 | 60.8 |
| WVC-659 | do. | 106.7 | 1.37 | MF | -- | 30.6 | 62.7 |
| | | | | MAF | -- | 32.8 | 67.2 |
| | | | | AR | 4.5 | 28.5 | 61.4 |
| WVC-608 | Beckley (?) | 71.4 | 1.35 | MF | -- | 29.8 | 64.3 |
| | | | | MAF | -- | 31.7 | 68.3 |
| | | | | AR | 8.1 | 26.4 | 58.8 |
| WVC-634 | do. | 71.1 | 1.35 | MF | -- | 28.7 | 64.1 |
| | | | | MAF | -- | 30.9 | 69.1 |
| | | | | AR | 10.3 | 26.0 | 58.8 |
| WVC-651 | do. | 78.7 | 1.39 | MF | -- | 29.0 | 65.6 |
| | | | | MAF | -- | 30.7 | 69.3 |
| | | | | AR | 2.7 | 29.6 | 62.3 |
| WVC-613 | Fire Creek (?) | 147.3 | 1.34 | MF | -- | 30.5 | 63.9 |
| | | | | MAF | -- | 32.5 | 67.7 |
| | | | | AR | 2.4 | 29.8 | 61.7 |
| WVC-614 | do. | 144.8 | 1.34 | MF | -- | 30.5 | 63.3 |
| | | | | MAF | -- | 32.6 | 67.4 |
| | | | | AR | 5.4 | 25.7 | 61.3 |
| WVC-616 | do. | 35.6 3/ | 1.39 | MF | -- | 27.2 | 64.8 |
| | | | | MAF | -- | 29.6 | 70.4 |
| | | | | AR | 4.3 | 25.8 | 59.9 |
| WVC-617 | do. | 50.8 4/ | 1.39 | MF | -- | 26.9 | 62.6 |
| | | | | MAF | -- | 30.1 | 69.9 |
| | | | | AR | 6.0 | 25.3 | 53.9 |
| WVC-623 | Pocahontas | 157.5 | 1.44 | MF | -- | 26.9 | 57.4 |
| | No. 3 (?) | | | MAF | -- | 31.9 | 68.1 |
| | | | | AR | 3.5 | 15.5 | 66.7 |
| WVC-624 | do. | 153.7 | 1.40 | MF | -- | 16.1 | 69.1 |
| | | | | MAF | -- | 18.9 | 81.1 |

1/ AR = As received; MF = Moisture free; MAF = Moisture and ash free.
2/ By atomic absorption analyses.
3/ Upper bench of coalbed at sample locality WVC-616 and 617.
4/ Lower bench of coalbed at sample locality WVC-616 and 617.

*Wilderness Study Area, W. Va.*

**Analysis (formerly U.S. Bureau of Mines, Coal Preparation and Analysis Group), Pittsburgh, outcrops. An attempt was made to penetrate the coal bed at least 0.3 meter to lessen the**

| Ultimate (percent) | | | | | | | Sulfur forms (percent)2/ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ash | Hydrogen | Carbon | Nitrogen | Oxygen | Sulfur | Calorific value Btu/lb | Sulfate | Pyritic | Organic | Ash softening temperature (°F) | Free-swelling index |
| 5.8 | 5.3 | 75.2 | 1.5 | 11.5 | 0.8 | 13,213 | 0.01 | 0.19 | 0.56 | | |
| 6.2 | 4.9 | 80.2 | 1.6 | 6.3 | .8 | 14,098 | .01 | .21 | .60 | 2,510 | 3.5 |
| -- | 5.2 | 85.5 | 1.7 | 6.7 | .9 | 15,027 | .01 | .22 | .64 | | |
| 5.1 | 5.3 | 75.1 | 1.5 | 12.1 | .8 | 13,187 | .01 | .19 | .57 | | |
| 5.5 | 4.9 | 80.5 | 1.6 | 6.6 | .8 | 14,136 | .01 | .21 | .61 | 2,460 | 2.5 |
| -- | 5.2 | 85.2 | 1.7 | 7.0 | .9 | 14,955 | .01 | .22 | .64 | | |
| 6.5 | 5.2 | 78.0 | 1.5 | 7.9 | .9 | 13,873 | .00 | .23 | .62 | | |
| 6.7 | 5.0 | 80.5 | 1.5 | 5.3 | .9 | 14,317 | .00 | .24 | .64 | 2,910 | 8.0 |
| -- | 5.4 | 86.4 | 1.6 | 5.7 | .9 | 15,352 | .00 | .26 | .69 | | |
| 5.6 | 5.5 | 78.8 | 1.3 | 7.8 | .9 | 13,974 | .01 | .33 | .53 | | |
| 5.9 | 5.3 | 82.5 | 1.4 | 4.0 | .9 | 14,628 | .01 | .35 | .56 | 2,800+ | 9.0 |
| -- | 5.6 | 87.6 | 1.5 | 4.3 | 1.0 | 15,539 | .01 | .37 | .59 | | |
| 6.7 | 5.3 | 74.6 | 1.3 | 11.6 | .6 | 13,111 | .01 | .10 | .50 | | |
| 7.2 | 4.8 | 81.2 | 1.4 | 4.8 | .7 | 14,264 | .01 | .11 | .54 | 2,910 | 8.5 |
| -- | 5.2 | 87.5 | 1.5 | 5.1 | .7 | 15,379 | .01 | .12 | .58 | | |
| 4.9 | 5.2 | 71.4 | 1.1 | 16.9 | .5 | 12,312 | .02 | .04 | .47 | | |
| 5.4 | 4.6 | 79.6 | 1.2 | 8.7 | .6 | 13,721 | .02 | .04 | .53 | 2,910 | .5 |
| -- | 4.8 | 84.1 | 1.3 | 9.2 | .6 | 14,507 | .02 | .04 | .56 | | |
| 5.4 | 5.4 | 80.5 | 1.4 | 6.6 | .7 | 14,383 | .01 | .17 | .54 | | |
| 5.6 | 5.2 | 82.7 | 1.4 | 4.3 | .7 | 14,777 | .01 | .17 | .56 | 2,800+ | 9.0 |
| -- | 5.5 | 87.6 | 1.5 | 4.6 | .8 | 15,650 | .01 | .18 | .59 | | |
| 6.1 | 5.4 | 80.3 | 1.4 | 6.2 | .6 | 14,284 | .01 | .17 | .46 | | |
| 6.2 | 5.2 | 82.3 | 1.4 | 4.2 | .7 | 14,628 | .01 | .17 | .48 | 2,800+ | 9.0 |
| -- | 5.6 | 87.7 | 1.5 | 4.5 | .7 | 15,597 | .01 | .18 | .51 | | |
| 7.6 | 5.0 | 74.8 | 1.4 | 10.3 | .9 | 13,141 | .01 | .16 | .68 | | |
| 8.0 | 4.6 | 79.1 | 1.5 | 5.8 | .9 | 13,891 | .01 | .17 | .72 | 2,800+ | 3.5 |
| -- | 5.0 | 86.0 | 1.7 | 6.3 | 1.0 | 15,106 | .01 | .19 | .78 | | |
| 10.0 | 5.0 | 74.4 | 1.4 | 8.6 | .6 | 13,135 | .01 | .17 | .46 | | |
| 10.5 | 4.7 | 77.7 | 1.5 | 5.0 | .7 | 13,722 | .01 | .17 | .48 | 2,800+ | 7.0 |
| -- | 5.2 | 86.8 | 1.6 | 5.6 | .7 | 15,331 | .01 | .19 | .53 | | |
| 14.8 | 4.8 | 68.4 | 1.0 | 10.4 | .7 | 12,043 | .01 | .16 | .48 | | |
| 15.7 | 4.4 | 72.8 | 1.0 | 5.3 | .7 | 12,815 | .01 | .17 | .52 | 2,800+ | 7.5 |
| -- | 5.2 | 86.4 | 1.2 | 6.3 | .8 | 15,209 | .01 | .20 | .61 | | |
| 14.3 | 4.9 | 71.4 | 1.0 | 7.6 | .8 | 12,572 | .01 | .29 | .47 | | |
| 14.8 | 4.6 | 74.0 | 1.1 | 4.7 | .8 | 13,022 | .01 | .30 | .49 | 2,800+ | 9.0 |
| -- | 5.4 | 86.8 | 1.3 | 5.5 | .9 | 15,288 | .01 | .36 | .57 | | |

TABLE 3.—*Coal washability characteristics,*

| Sample locality number | Coalbed | Specific gravity fractions | | Dry basis (percent) | | |
|---|---|---|---|---|---|---|
| | | Sink | Float | Weight | Ash | Sulfur |
| Laurelly Branch adit, same locality as WVC-626 and 627[2/] | Little Raleigh (?) | | | | | |
| | | -- | 1.35 | 72.83 | 3.19 | 0.87 |
| | | 1.35 | 1.40 | 6.81 | 12.48 | .81 |
| | | 1.40 | 1.45 | 10.05 | 17.58 | .85 |
| | | 1.45 | 1.50 | 2.47 | 20.85 | .83 |
| | | 1.50 | 1.55 | .68 | 24.81 | 1.39 |
| | | 1.55 | -- | 7.16 | 37.49 | 1.60 |
| Do.[2/] | do. | | | | | |
| | | -- | 1.35 | 83.86 | 2.21 | .87 |
| | | 1.35 | 1.40 | 5.89 | 10.05 | .80 |
| | | 1.40 | 1.45 | 4.21 | 14.45 | .80 |
| | | 1.45 | 1.50 | 1.47 | 17.59 | .80 |
| | | 1.50 | 1.55 | .98 | 19.30 | .82 |
| | | 1.55 | -- | 3.59 | 40.19 | 4.00 |
| Do.[2/] | do. | | | | | |
| | | -- | 1.35 | 79.46 | 2.57 | .87 |
| | | 1.35 | 1.40 | 6.26 | 11.10 | .80 |
| | | 1.40 | 1.45 | 6.54 | 16.37 | .83 |
| | | 1.45 | 1.50 | 1.87 | 19.31 | .82 |
| | | 1.50 | 1.55 | .86 | 21.04 | 1.00 |
| | | 1.55 | -- | 5.01 | 38.65 | 2.63 |
| Drill hole CW-104[3/] | do. | -- | 1.30 | 77.2 | 2.01 | .85 |
| | | 1.30 | 1.35 | 9.0 | 6.74 | .92 |
| | | 1.35 | 1.40 | 2.8 | 9.43 | .94 |
| | | 1.40 | 1.45 | 1.3 | 13.02 | .91 |
| | | 1.45 | 1.50 | 1.7 | 21.93 | 1.02 |
| | | 1.50 | 1.55 | 1.5 | 27.86 | .59 |
| | | 1.55 | 1.60 | 1.0 | 30.67 | .59 |
| | | 1.60 | -- | 5.5 | 54.58 | .49 |
| Drill hole CW-110[3/] | do. | -- | 1.30 | 61.4 | 1.78 | .78 |
| | | 1.30 | 1.35 | 11.6 | 5.77 | .79 |
| | | 1.35 | 1.40 | 7.6 | 10.87 | .76 |
| | | 1.40 | 1.45 | 4.1 | 13.03 | .65 |
| | | 1.45 | 1.50 | 2.2 | 14.16 | .59 |
| | | 1.50 | 1.55 | 1.1 | 16.25 | .40 |
| | | 1.55 | 1.60 | 1.0 | 24.31 | .35 |
| | | 1.60 | -- | 11.0 | 56.71 | .41 |

*Cranberry Wilderness Study Area, W. Va.*[1]

| Cumulative data (percent) | | | | | | |
|---|---|---|---|---|---|---|
| Float | | | Sink | | | |
| Weight | Ash | Sulfur | Weight | Ash | Sulfur | Remarks |
| | | | 100.00 | 8.31 | 0.92 | Plus 1/4 inch round = |
| 72.83 | 3.19 | 0.87 | 27.17 | 22.03 | 1.05 | 39.88% of total sample |
| 79.64 | 3.98 | .86 | 20.36 | 25.22 | 1.13 | |
| 89.69 | 5.51 | .86 | 10.31 | 32.67 | 1.40 | |
| 92.16 | 5.92 | .86 | 7.84 | 36.39 | 1.58 | |
| 92.84 | 6.06 | .87 | 7.16 | 37.49 | 1.60 | |
| 100.00 | 8.31 | .92 | | | | |
| | | | 100.00 | 4.94 | .97 | 1/4 inch round by 0 = |
| 83.86 | 2.21 | .87 | 16.14 | 19.15 | 1.51 | 60.12% of total sample |
| 89.75 | 2.72 | .87 | 10.25 | 24.38 | 1.92 | |
| 93.96 | 3.25 | .86 | 6.04 | 31.30 | 2.71 | |
| 95.43 | 3.47 | .86 | 4.57 | 35.71 | 3.32 | |
| 96.41 | 3.63 | .86 | 3.59 | 40.19 | 4.00 | |
| 100.00 | 4.94 | .97 | | | | |
| | | | 100.00 | 6.29 | .95 | Calculated composite = |
| 79.46 | 2.57 | .87 | 20.54 | 20.66 | 1.27 | 100% of total sample |
| 85.72 | 3.19 | .86 | 14.28 | 24.85 | 1.47 | |
| 92.26 | 4.13 | .86 | 7.74 | 32.02 | 2.01 | |
| 94.13 | 4.43 | .86 | 5.87 | 36.07 | 2.39 | |
| 94.99 | 4.58 | .86 | 5.01 | 38.65 | 2.63 | |
| 100.00 | 6.29 | .95 | | | | |
| 77.2 | 2.01 | .85 | 100.0 | 6.69 | .84 | Composite 3/4 inch round |
| 86.2 | 2.50 | .86 | 22.8 | 22.54 | .79 | by 0 = 100% of core |
| 89.0 | 2.72 | .86 | 13.8 | 32.85 | .70 | crushed to 3/4 inch |
| 90.3 | 2.87 | .86 | 11.0 | 38.81 | .64 | round |
| 92.0 | 3.22 | .86 | 9.7 | 42.26 | .61 | |
| 93.5 | 3.62 | .86 | 8.0 | 46.58 | .52 | |
| 94.5 | 3.90 | .86 | 6.5 | 50.90 | .51 | |
| 100.0 | 6.69 | .84 | 5.5 | 54.58 | .49 | |
| 61.4 | 1.78 | .78 | 100.0 | 10.09 | .72 | Composite 3/4 inch round |
| 73.0 | 2.41 | .78 | 38.6 | 23.32 | .63 | by 0 = 100% of core |
| 80.6 | 3.21 | .78 | 27.0 | 30.86 | .56 | crushed to 3/4 inch |
| 84.7 | 3.69 | .77 | 19.4 | 38.69 | .48 | round |
| 86.9 | 3.95 | .77 | 15.3 | 45.57 | .43 | |
| 88.0 | 4.11 | .76 | 13.1 | 50.84 | .40 | |
| 89.0 | 4.33 | .76 | 12.0 | 54.01 | .41 | |
| 100.0 | 10.09 | .72 | 11.0 | 56.71 | .41 | |

TABLE 3.—*Coal washability characteristics, Cranberry*

| Sample locality number | Coalbed | Specific gravity fractions | | Dry basis (percent) | | |
|---|---|---|---|---|---|---|
| | | Sink | Float | Weight | Ash | Sulfur |
| Drill hole CW-116[3/] | Little Raleigh (?) | -- | 1.30 | 37.4 | 3.06 | 0.76 |
| | | 1.30 | 1.35 | 17.0 | 6.90 | .77 |
| | | 1.35 | 1.40 | 8.9 | 12.22 | .72 |
| | | 1.40 | 1.45 | 4.0 | 16.78 | .69 |
| | | 1.45 | 1.50 | 2.3 | 22.58 | .78 |
| | | 1.50 | 1.55 | 1.7 | 26.81 | .73 |
| | | 1.55 | 1.60 | 1.3 | 32.34 | .78 |
| | | 1.60 | -- | 27.4 | 66.20 | .34 |
| Tumbling Rock Run adit, same locality as WVC-613 and 614[4/] | Fire Creek (?) | -- | 1.40 | | | |
| | | 1.40 | 1.45 | 92.57 | 5.00 | .80 |
| | | 1.45 | 1.50 | 1.95 | 16.32 | 1.36 |
| | | 1.50 | 1.55 | .62 | 24.93 | 1.31 |
| | | 1.55 | -- | 4.86 | 62.10 | 3.02 |
| Drill hole CW-117[3/] | Pocahontas No. 3 (?) | -- | 1.30 | 30.2 | 2.44 | .66 |
| | | 1.30 | 1.35 | 27.6 | 6.13 | .61 |
| | | 1.35 | 1.40 | 8.9 | 10.51 | .51 |
| | | 1.40 | 1.45 | 5.7 | 15.17 | .47 |
| | | 1.45 | 1.50 | 3.7 | 19.95 | .47 |
| | | 1.50 | 1.55 | 4.0 | 26.29 | .55 |
| | | 1.55 | 1.60 | 5.3 | 31.59 | .46 |
| | | 1.60 | -- | 14.6 | 40.87 | .35 |
| Drill hole CW-118[3/] | do. | -- | 1.30 | 17.7 | 2.42 | .74 |
| | | 1.30 | 1.35 | 34.3 | 6.86 | .66 |
| | | 1.35 | 1.40 | 18.8 | 11.29 | .58 |
| | | 1.40 | 1.45 | 9.7 | 14.94 | .50 |
| | | 1.45 | 1.50 | 4.6 | 18.77 | .48 |
| | | 1.50 | 1.55 | 2.2 | 22.97 | .44 |
| | | 1.55 | 1.60 | 1.3 | 24.93 | .40 |
| | | 1.60 | -- | 11.4 | 74.70 | .36 |
| Hunting Run adit, same locality as WVC-624[4/] | do. | -- | 1.35 | | | |
| | | 1.35 | 1.40 | 72.49 | 7.99 | .91 |
| | | 1.40 | 1.45 | 1.86 | 18.11 | .94 |
| | | 1.45 | 1.50 | 4.36 | 24.49 | .96 |
| | | 1.50 | 1.55 | 2.74 | 26.73 | .85 |
| | | 1.55 | -- | 18.55 | 49.81 | .74 |

1/ All washability data provided by Mid Allegheny Corporation, Summersville, W. Va.
2/ Analyses performed by Standard Laboratories, Inc., Charleston, W. Va.
3/ Analyses performed by Commercial Testing and Engineering Co., Charleston, W. Va.
4/ Analyses performed by the Powellton Company, Mallory, W. Va.

*Wilderness Study Area, W. Va.*[1]—Continued

| Cumulative data (percent) | | | | | | |
|---|---|---|---|---|---|---|
| Float | | | Sink | | | |
| Weight | Ash | Sulfur | Weight | Ash | Sulfur | Remarks |
| 37.4 | 3.06 | 0.76 | 100.0 | 23.61 | 0.64 | Composite 3/4 inch round by 0 = 100% of core crushed to 3/4 inch round |
| 54.4 | 4.26 | .76 | 62.6 | 35.89 | .57 | |
| 63.3 | 5.38 | .76 | 45.6 | 46.70 | .49 | |
| 67.3 | 6.06 | .75 | 36.7 | 55.06 | .44 | |
| 69.6 | 6.60 | .75 | 32.7 | 59.74 | .41 | |
| 71.3 | 7.08 | .75 | 30.4 | 62.55 | .38 | |
| 72.6 | 7.54 | .75 | 28.7 | 64.67 | .36 | |
| 100.0 | 23.61 | .64 | 27.4 | 66.20 | .34 | |
| | | | 100.00 | 8.04 | .92 | 3/4 inch by 0 = total bulk sample |
| 92.57 | 5.00 | .80 | 7.43 | 45.94 | 2.37 | |
| 94.52 | 5.24 | .81 | 5.48 | 57.35 | 2.78 | |
| 95.14 | 5.35 | .82 | 4.86 | 62.10 | 3.02 | |
| 100.00 | 8.04 | .92 | | | | |
| 30.2 | 2.44 | .66 | 100.0 | 13.66 | .55 | Composite 3/4 inch round by 0 = 100% of core crushed to 1 inch round |
| 57.8 | 4.20 | .64 | 69.8 | 18.51 | .51 | |
| 66.7 | 5.04 | .62 | 42.2 | 26.61 | .44 | |
| 72.4 | 5.84 | .61 | 33.3 | 30.92 | .43 | |
| 76.1 | 6.53 | .60 | 27.6 | 34.17 | .42 | |
| 80.1 | 7.51 | .60 | 23.9 | 36.37 | .41 | |
| 85.4 | 9.01 | .59 | 19.9 | 38.40 | .38 | |
| 100.0 | 13.66 | .55 | 14.6 | 40.87 | .35 | |
| 17.7 | 2.42 | .74 | 100.0 | 16.56 | .59 | Composite 3/4 inch round by 0 = 100% of core crushed to 3/4 inch round |
| 52.0 | 5.35 | .69 | 82.3 | 19.60 | .56 | |
| 70.8 | 6.93 | .66 | 48.0 | 28.71 | .49 | |
| 80.5 | 7.89 | .64 | 29.2 | 39.92 | .43 | |
| 85.1 | 8.48 | .63 | 19.5 | 52.35 | .40 | |
| 87.3 | 8.85 | .63 | 14.9 | 62.72 | .38 | |
| 88.6 | 9.08 | .62 | 12.7 | 69.61 | .36 | |
| 100.0 | 16.56 | .59 | 11.4 | 74.70 | .36 | |
| | | | 100.00 | 17.17 | -- | 3/4 inch by 0 = total bulk sample |
| 72.49 | 7.99 | .91 | 27.51 | 41.36 | -- | |
| 74.35 | 8.24 | .91 | 25.65 | 43.04 | -- | |
| 78.71 | 9.14 | .91 | 21.29 | 46.84 | -- | |
| 81.45 | 9.73 | .91 | 18.55 | 49.81 | -- | |
| 100.00 | 17.17 | .88 | | | | |

Data as reported with no independent rounding by the Bureau of Mines.

TABLE 4.—*Analyses of coal ash, Cranberry*

[Analyses performed by U.S. Bureau of Mines, Reno Metallurgy Research Center, Reno, Nev. include: As(.009), Bi(.08), Cd(.002), Ga(.001), La(.02), Mo.(.004), Na(2), Nb(.05), P(.2). Si occurs in all samples in amounts greater than 29 percent. A possible error of plus 100 than; <, less than].

| Sample number | Coalbed | Sample interval (centimeters) | General | | |
|---|---|---|---|---|---|
| | | | Al | B | Ba |
| WVC-626 | Little Raleigh (?) | 106.7 | 21 | 0.02 | 0.2 |
| WVC-627 | do. | 105.4 | 24 | .02 | .2 |
| WVC-659 | do. | 106.7 | 26 | .02 | .2 |
| WVC-608 | Beckley (?) | 71.4 | 18 | <.02 | .4 |
| WVC-634 | do. | 78.7 | 27 | <.02 | .4 |
| WVC-651 | do. | 71.1 | 24 | <.02 | .4 |
| WVC-613 | Fire Creek (?) | 147.3 | 21 | .02 | .1 |
| WVC-614 | do. | 144.8 | 24 | .02 | .1 |
| WVC-616 | do. | 35.6 1/ | 27 | <.02 | .09 |
| WVC-617 | do. | 50.8 2/ | 22 | <.03 | .08 |
| WVC-623 | Pocahontas No. 3 (?) | 157.5 | >27 | <.02 | .2 |
| WVC-624 | do. | 153.7 | 24 | .02 | .04 |

| Sample number | Coalbed | Sample interval (centimeters) |
|---|---|---|
| WVC-626 | Little Raleigh (?) | 106.7 |
| WVC-627 | do. | 105.4 |
| WVC-659 | do. | 106.7 |
| WVC-608 | Beckley (?) | 71.4 |
| WVC-634 | do. | 78.7 |
| WVC-651 | do. | 71.1 |
| WVC-613 | Fire Creek (?) | 147.3 |
| WVC-614 | do. | 144.8 |
| WVC-616 | do. | 35.6 1/ |
| WVC-617 | do. | 50.8 2/ |
| WVC-623 | Pocahontas No. 3 (?) | 157.5 |
| WVC-624 | do. | 153.7 |

1/ Upper bench of coalbed at sample locality WVC-616 and 617.
2/ Lower bench of coalbed at sample locality WVC-616 and 617.

*Wilderness Study Area, W. Va.*

**Elements tested for but occurring in amounts below the lower detection limit (in parentheses) Pd(.001), Pt(.004), Sb(.05), Sc(.001), Sn(.007), Ta(.05), Te(.1), W(.06), Y(.007), Zr(.005). percent to minus 50 percent of reported concentration is assumed. Symbols used; >, greater**

| spectrographic analyses (percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Be | Ca | Co | Cr | Cu | K | Li | Mg | Mn |
| 0.002 | 1.0 | <0.001 | 0.02 | 0.03 | 3 | <0.005 | 2.0 | 0.2 |
| .002 | 1.0 | <.001 | .02 | .02 | 9 | <.005 | 1.0 | .06 |
| .002 | .7 | .007 | .03 | .03 | 5 | .03 | 1.0 | <.001 |
| .003 | .9 | .009 | .02 | .02 | 3 | .02 | 1.0 | .03 |
| .002 | 1.0 | .006 | .04 | <.001 | 5 | <.005 | 1.0 | .04 |
| .002 | 2.0 | .01 | .02 | .006 | 5 | .01 | 2.0 | .03 |
| .002 | .6 | .001 | .03 | .09 | 4 | .06 | 1.0 | .007 |
| .002 | .5 | <.001 | .02 | .06 | 5 | .04 | .9 | .004 |
| .002 | .8 | <.001 | .02 | <.001 | 11 | .02 | 1.0 | .07 |
| .002 | .4 | <.003 | .02 | <.001 | 3 | <.005 | 1.0 | <.001 |
| .001 | .5 | <.001 | .02 | <.001 | 5 | .03 | 1.0 | .004 |
| <.001 | .3 | <.001 | .02 | .008 | 4 | .07 | 1.0 | .009 |

| General spectrographic analyses (percent) | | | | | | Spectrographic Ge | Radiometric $U_3O_8$ |
|---|---|---|---|---|---|---|---|
| Ni | Pb | Sr | Ti | V | Zn | (ppm) | (percent) |
| 0.009 | <0.03 | 0.04 | 2 | 0.08 | 0.04 | <10 | 0.003 |
| .01 | <.03 | .04 | 2 | .08 | .02 | 12 | .003 |
| .01 | <.01 | .07 | 2 | .08 | <.001 | 14 | .003 |
| .01 | .01 | .2 | 1 | .03 | .04 | 45 | .003 |
| .01 | <.01 | .2 | 2 | .07 | <.001 | 43 | .004 |
| .02 | <.01 | .2 | 2 | .02 | .01 | 20 | .002 |
| .004 | .02 | .05 | 2 | .05 | .003 | 15 | .004 |
| .004 | .02 | .05 | 2 | .05 | <.001 | 17 | .004 |
| .008 | <.01 | .04 | 3 | .05 | <.001 | <10 | .003 |
| .009 | <.03 | .03 | 2 | .03 | <.001 | 10 | .003 |
| .006 | <.01 | .08 | 3 | .02 | .001 | 10 | .003 |
| .005 | <.01 | .04 | 3 | .02 | <.001 | <10 | .003 |

Laurelly Branch. Areas underlain by coal assigned to the reserve base are shown in figure 8.

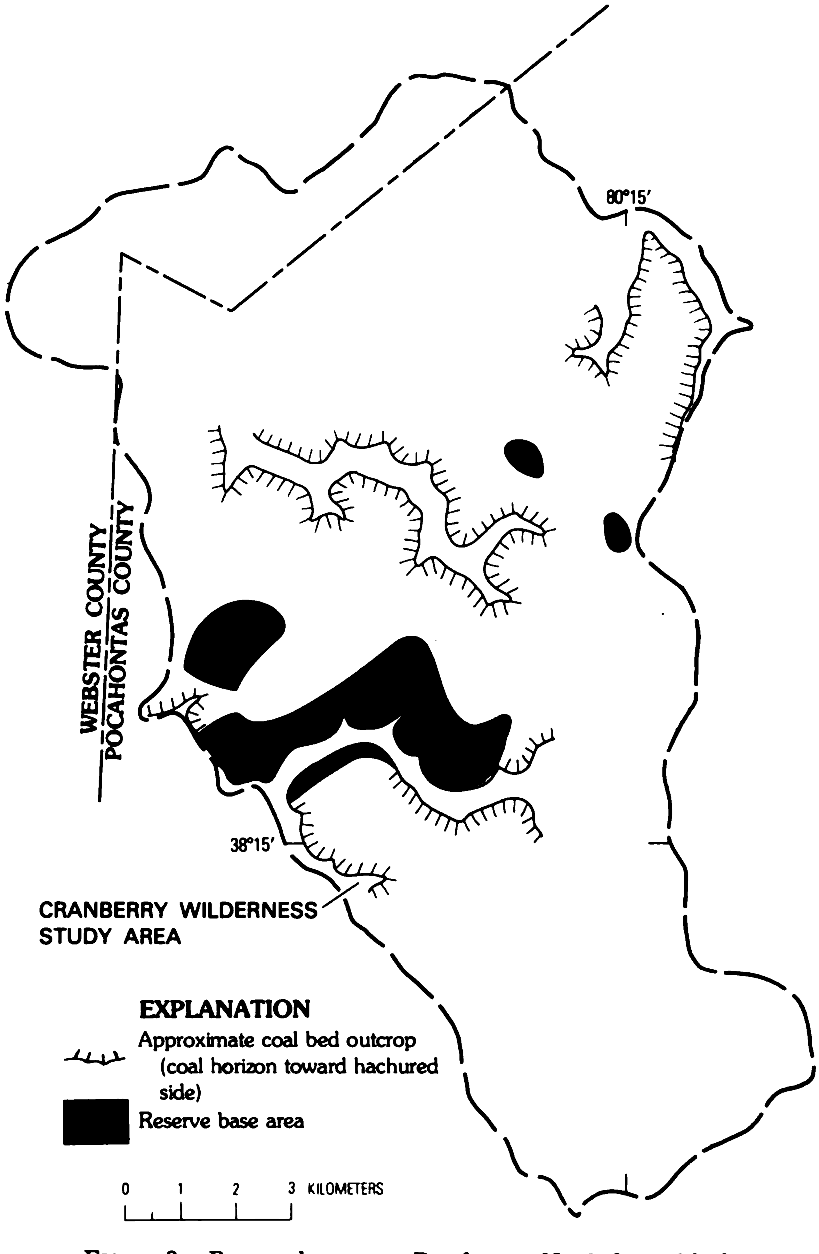



FIGURE 8.—Reserve base area, Pocahontas No. 3 (?) coal bed.

The estimates for the coal resources, reserve base, and reserves for the Pocahontas No. 3 coal bed are as follows:

| | *Metric tons* |
|---|---|
| Coal resources | 20,490,000 |
| Reserve base | 13,586,000 |
| Reserves | [1] 6,531,000 |

[1] The estimate for reserves excludes the two small northernmost blocks because they are considered too small to be economically minable.

The potential for mining this coal bed is high because of the large estimated reserve tonnages and good surface access. The reserves would be accessible to mining only from mine entries within the study boundary.

Pocahontas No. 3(?) coal bed samples WVC–623 and WVC–624 (table 2) were collected adjacent to caved adits. Coal from the bed is tentatively ranked as medium-volatile bituminous; however, fixed carbon values show a large variation that may be due to the weathered condition of the samples. The analytical data indicate that the coal has a low sulfur content and a high ash content. The washability tests (table 3) show that the coal can be cleaned to meet marginal- to premium-grade coking coal standards.

### POCAHONTAS NO. 3(?) RIDER COAL BED

The Pocahontas No. 3(?) rider generally lies about 5 m above the Pocahontas No. 3(?). The bed thickness ranges from 0 to 107 cm and locally includes a shale parting 5–8 cm thick. A pod of thin coal identified as the Pocahontas No. 3(?) rider underlies mountainsides near the east-central boundary of the area (pl. 3). Coal of minable thickness is located only along the Cranberry River in the west-central part of the area (fig. 9).

The estimates for the coal resources, reserve base, and reserves for the Pocahontas No. 3(?) rider coal bed are as follows:

| | *Metric tons* |
|---|---|
| Coal resources | 1,034,000 |
| Reserve base | 525,000 |
| Reserves | 263,000 |

The reserves identified during this study are confined to a small block accessible to mining only from entries within the study area. Recovery could be possible in conjunction with deep mining of the underlying Pocahontas No. 3(?) coal bed.

### LITTLE FIRE CREEK(?) COAL BED

Little Fire Creek(?) coal bed lies from 3 to 49 m above the base of the New River Formation. The bed ranges in thickness

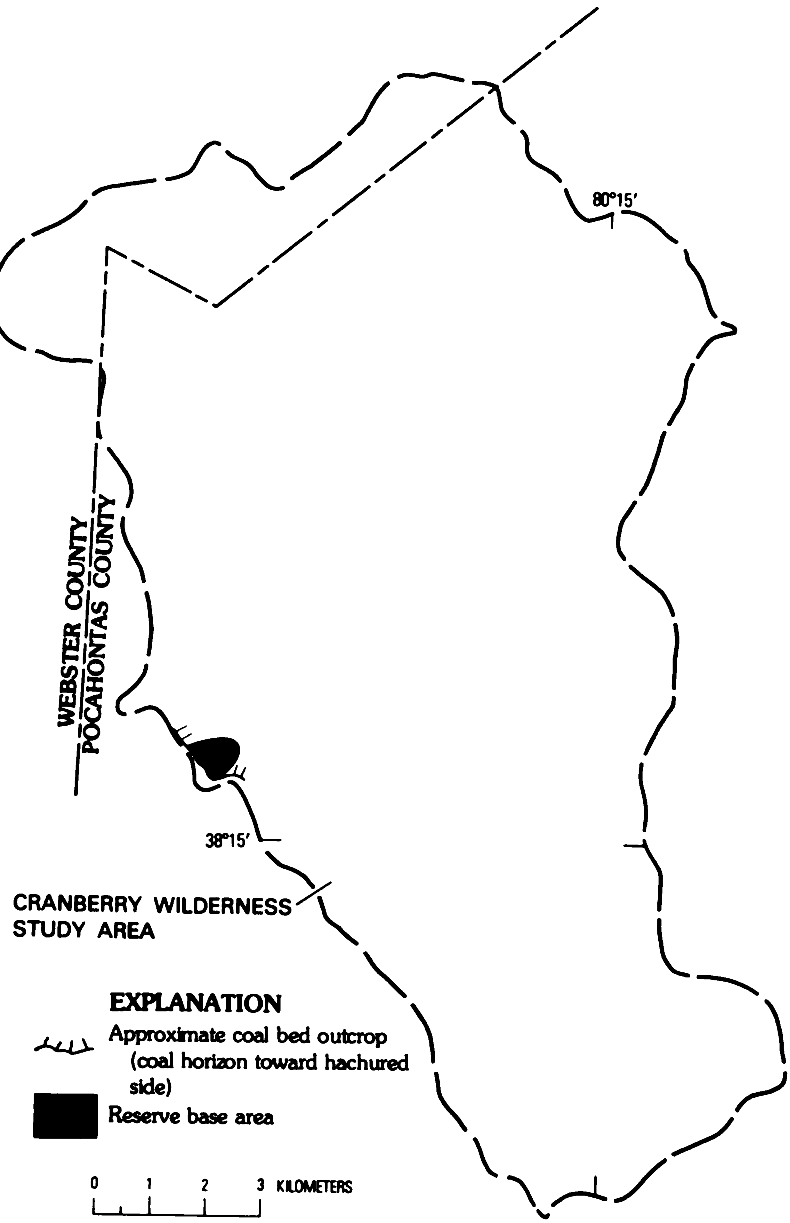



FIGURE 9.—Reserve base area, Pocahontas No. 3(?) rider coal bed.

from 0 to 97 cm and locally contains thin bony coal and shale partings. The bed underlies an area along the North Fork east of Cashcamp Run and at the head of the Middle Fork of the Williams

River (pl. 3). Coal of minable thickness lies along the east-central boundary of the study area (fig. 10).

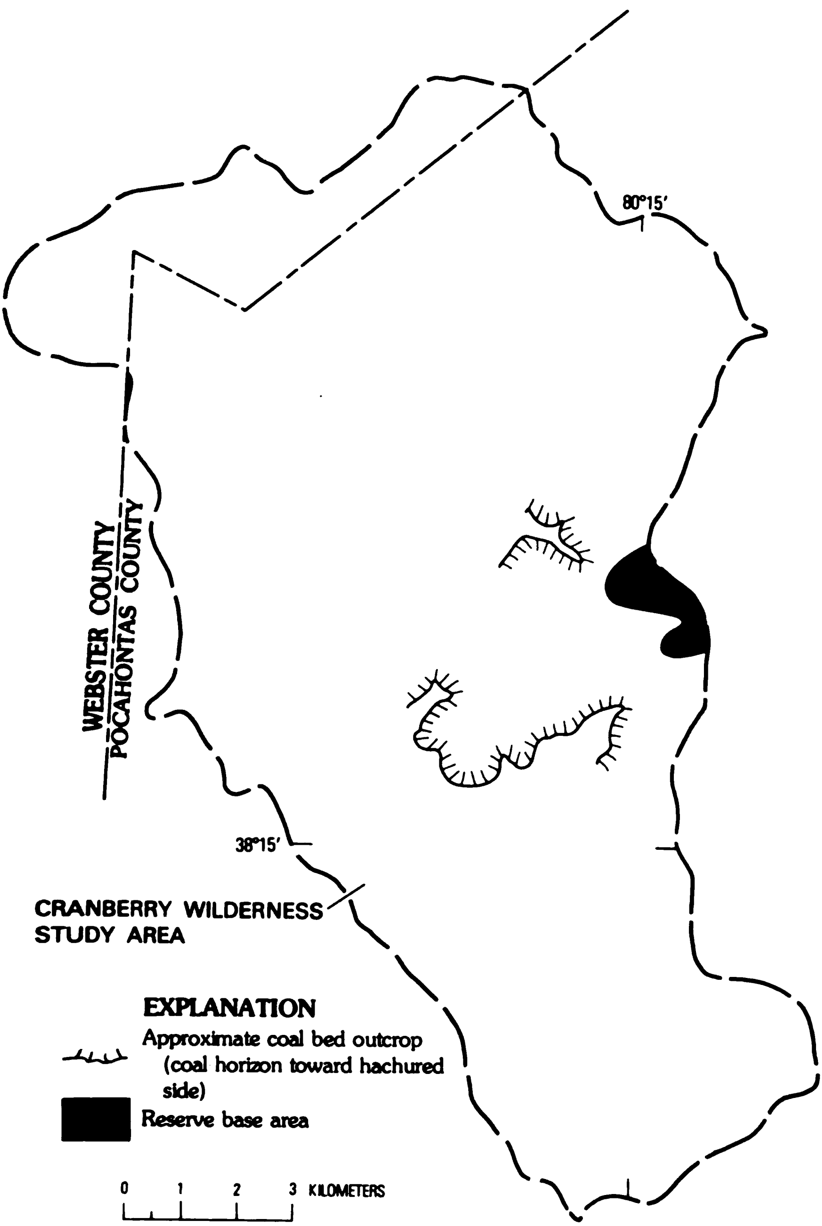



FIGURE 10.—Reserve base area, Little Fire Creek(?) coal bed.

The estimates for coal resources, reserve base, and reserves of the Little Fire Creek(?) coal bed are as follows:

| | Metric tons |
|---|---|
| Coal resources | 3,865,000 |
| Reserve base | 1,619,000 |
| Reserves | 810,000 |

This coal bed would be accessible by drift mining from entries outside the boundary of the study area. Mining from within the area would require the sinking of a vertical or inclined shaft.

### FIRE CREEK(?) COAL BED

The Fire Creek(?) coal bed occurs about 60 m above the Pocahontas No. 3(?) coal bed. Where present as a single bed, the coal thickness varies from 0 to 147 cm, but locally the coal splits into two or more beds. Although most of the study area is underlain by the Fire Creek(?), blocks containing coal 35 cm thick or more are widely separated (pl. 3). The bed crops out on the mountainsides along the North Fork, Tumbling Rock Run, Cranberry, Williams, and Middle Fork of the Williams Rivers. Reserve blocks occur mainly along Tumbling Rock Run, but two small blocks have been identified in the central and eastern parts of the area (fig. 11). The lateral extent of this coal bed has been defined by core drilling, except in the mountains east of the Cranberry River and south of the North Fork where there has been no drilling. A prospect pit in this part of the study area suggests that the Fire Creek(?) coal underlies these mountains. Isopachs projected southward from areas of both surface and subsurface control also suggest coal in this area.

The estimates for the coal resources, reserves base, and reserves of the Fire Creek(?) coal bed are as follows:

| | Metric tons |
|---|---|
| Coal resources | 22,243,000 |
| Reserve base | 2,079,000 |
| Reserves | 1,040,000 |

Coal reserves along Tumbling Rock Run would be accessible to mining only from entries within the area. The central reserve block has a small tonnage that lessens the potential for mining of this coal. The easternmost reserve block would be accessible to underground mining from entries outside the study boundary.

Four samples of the Fire Creek(?) coal bed were collected and their analyses are shown in table 2. Tentatively, the raw coal is ranked as high-volatile A to medium-volatile bituminous. Samples

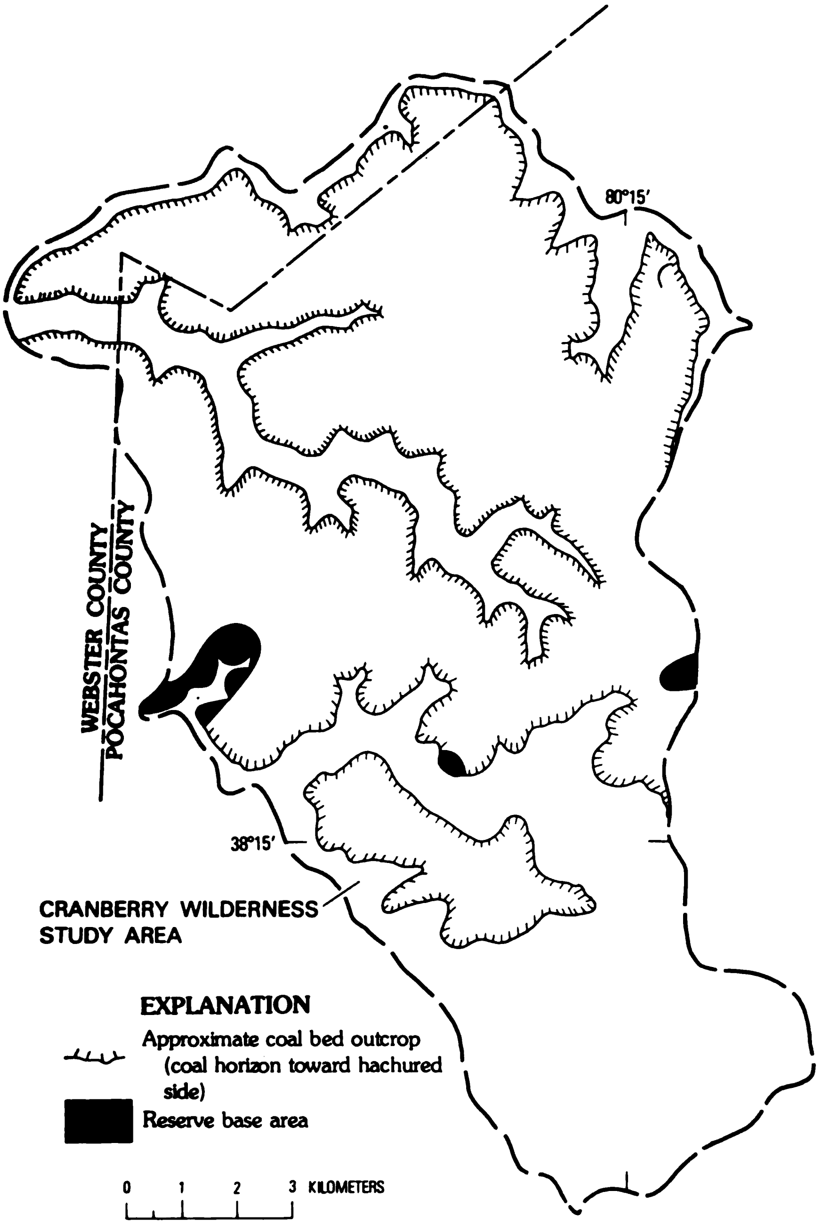



FIGURE 11.—Reserve base area, Fire Creek (?) coal bed.

WVC–613 and 614 were taken from opposite ribs at the face of the adit on Tumbling Rock Run (fig. 12). The coal has low sulfur and ash contents and is of premium coking-coal quality. Samples

FIGURE 12.—Adit along Tumbling Rock Run.

WVC–616 and 617 were taken from outside a caved adit on the north side of North Fork; WVC–616 is from the upper coal bench, WVC–617, the lower coal bench. These benches are separated by 11 cm of underclay. Both samples are low in sulfur, but have a moderate ash content, which may in part be due to weathering.

### BECKLEY(?) COAL BED

The Beckley(?) coal bed is about 18 to 24 m above the Fire Creek(?) and underlies most of the northern half of the area (pl. 3). Thickness ranges from 0 to 145 cm; thin shale partings are locally present. The thickest part of the bed lies in the east-central part of the study area, where it is of minable thickness (fig. 13).

In much of the northern quarter of the area, the bed is less than 35 cm thick and locally may be absent. At least 30 prospect trenches are known in the Beckley(?) along the mountainsides north of North Fork and the upper tributaries of Middle Fork. South of North Fork are no known drill holes or prospects, but isopachs projected in this area suggest that the bed is thin or absent.

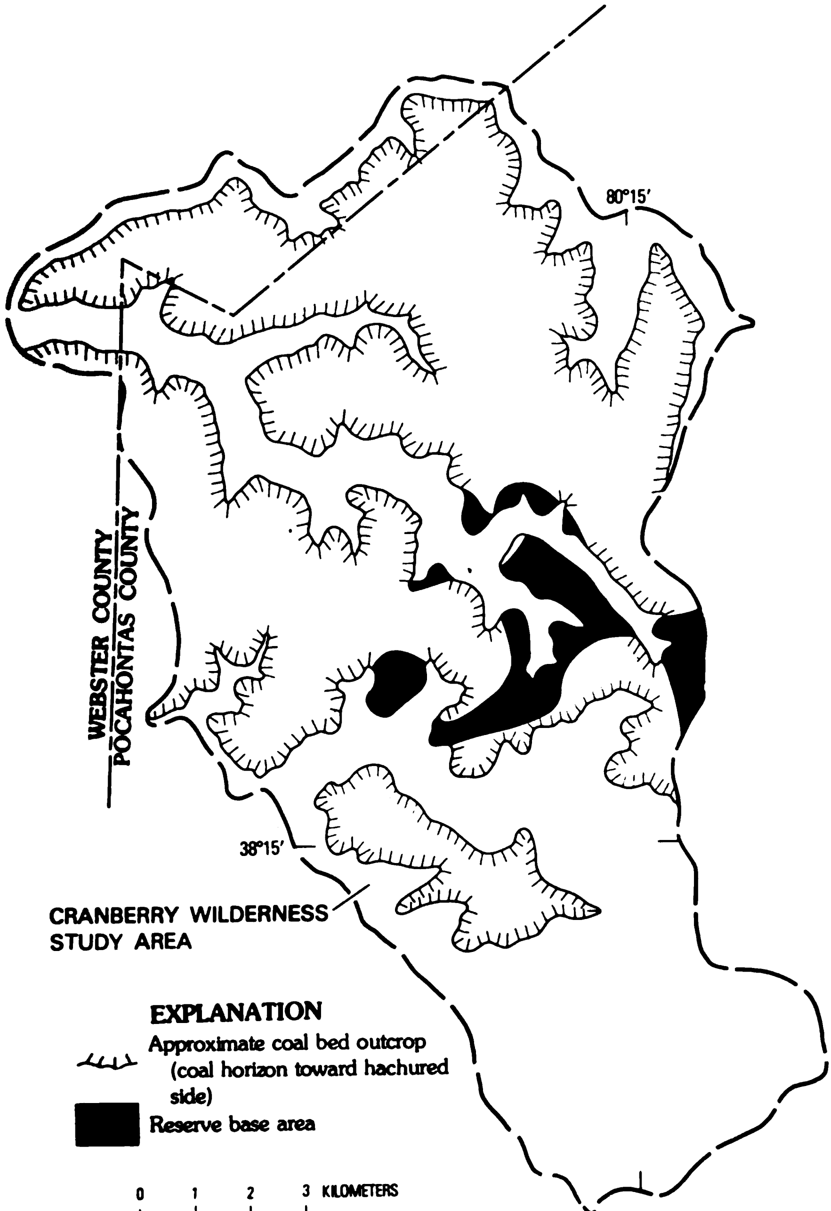



FIGURE 13.—Reserve base area, Beckley (?) coal bed.

The estimates for coal resources, reserve base, and reserves are:

| | *Metric tons* |
|---|---|
| Coal resources | 22,553,000 |
| Reserve base | 6,847,000 |
| Reserves | 3,424,000 |

Reserves would be easily accessible to underground mining from entries within the study boundary. The easternmost block of coal could also be mined from entries outside the area.

Three sample analyses, WVC–608, 634, and 651 (table 2), indicate that the raw coal can be ranked tentatively as medium-volatile bituminous. The coal bed has a low sulfur and ash content and is of premium coking-coal quality.

#### LITTLE RALEIGH(?) COAL BED

The Little Raleigh(?) coal bed lies about 55 m above the Beckley(?). The bed ranges in thickness from 0 to 107 cm, and contains sporadic thin partings of shale and bony coal. A bony coal layer, 5 to 30 cm thick, occurs in several areas below and, in some places, above the bed. The coal is split locally into three or more beds separated by as much as 5 m of intervening strata. Most of the resource and reserve base lies between the Middle Fork of the Williams River and Tumbling Rock Run (pl. 3 and fig. 14). Portions of the bed have been partly or entirely removed as a result of channel washouts that occurred during or shortly after the coal deposition.

The estimates for the coal resources, reserve base, and reserves of the Little Raleigh(?) coal bed are:

| | *Metric tons* |
|---|---|
| Coal resources | 17,193,000 |
| Reserve base | 8,449,000 |
| Reserves | 4,225,000 |

Areas having a bony coal layer at the top or bottom of the coal bed were excluded from these reserve base tonnages where the exclusion of the bony layer made the bed less than 70 cm thick.

A high potential exists for mining this coal bed. Underground-mining plans have been developed by Mid Allegheny Corp. for the large reserve base block between Laurelly Branch and Tumbling Rock Run and for the northwesternmost block. Coal in the northwesternmost and southwesternmost blocks would be accessible to mining from entries outside the study boundary; the remaining coal could be mined only from entries within the area.

Three samples, WVC–626, 627, and 659 (table 2), from inside adits indicate that the raw coal can be ranked tentatively as high-volatile A to medium-volatile bituminous. Sulfur and ash contents are low and the coal is of premium coking-coal quality. Washability tests for a bulk sample from an adit and three drill holes are shown in table 3.

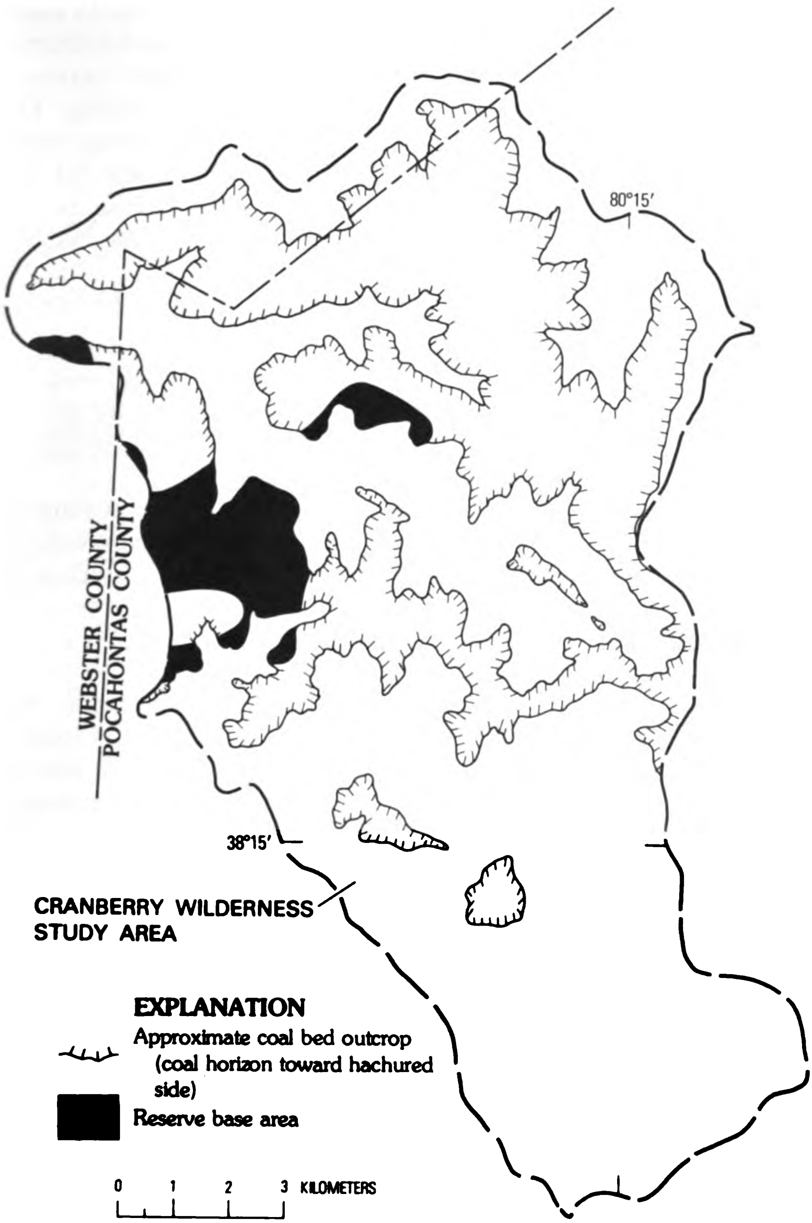



FIGURE 14.—Reserve base area, Little Raleigh (?) coal bed.

### LITTLE RALEIGH(?) RIDER COAL BED

The Little Raleigh (?) rider coal bed is generally from 6 to 12 m above the Little Raleigh(?). The bed ranges in thickness from

0 to 81 cm and in some areas consists of two or more splits separated by as much as 5 m. The coal generally is impure, and scattered thin shale and bony coal partings are present. Channel washouts have partly or completely removed the coal in some places. The thickest coal is along the east-central edge of the study area where the bed is free of partings and is as much as 81 cm thick (pl. 3). A small resource block occurs northwest of Hateful Run in the east-central part of the area. The area underlain by the coal reserve base is shown in figure 15.

The estimates for the coal resources, reserve base, and reserves of the Little Raleigh (?) rider are:

| | *Metric tons* |
|---|---|
| Coal resources | 2,638,000 |
| Reserve base | 1,074,000 |
| Reserves | 537,000 |

The limited reserve tonnage lessens the potential for mining of the Little Raleigh (?) rider. Mining would have to be from entries within the study boundary because of restrictions on mining at shallow depths below State Scenic Highway 150.

### SEWELL COAL BED

The Sewell coal bed occurs about 55 m above the Little Raleigh (?). The bed ranges in thickness from 0 to 69 cm, and locally contains thin bony coal and shale partings. Thickest coal occurs in two small pods, one in the northeast part of the study area and the other in the west-central part (pl. 3). None of the coal is considered to be of minable thickness.

The coal resources of the Sewell coal bed are 10,044,000 metric tons.

This bed was correlated into the area from known Sewell coal in mines and drill holes to the southwest. A marker bed of conglomeratic sandstone, which lies 0 to 15 m above the coal, aided in the correlation.

### HUGHES FERRY(?) COAL BED

The Hughes Ferry (?) coal bed occurs from 104 to 113 m above the Sewell. The bed ranges in thickness from 48 to 61 cm, and locally contains shale partings. This coal bed occurs only in a small area near the top of a ridge between Little Fork and Laurelly Branch (pl. 3). None of the coal is considered to be of minable thickness.

Coal resources of the Hughes Ferry (?) coal bed are 930,000 metric tons.

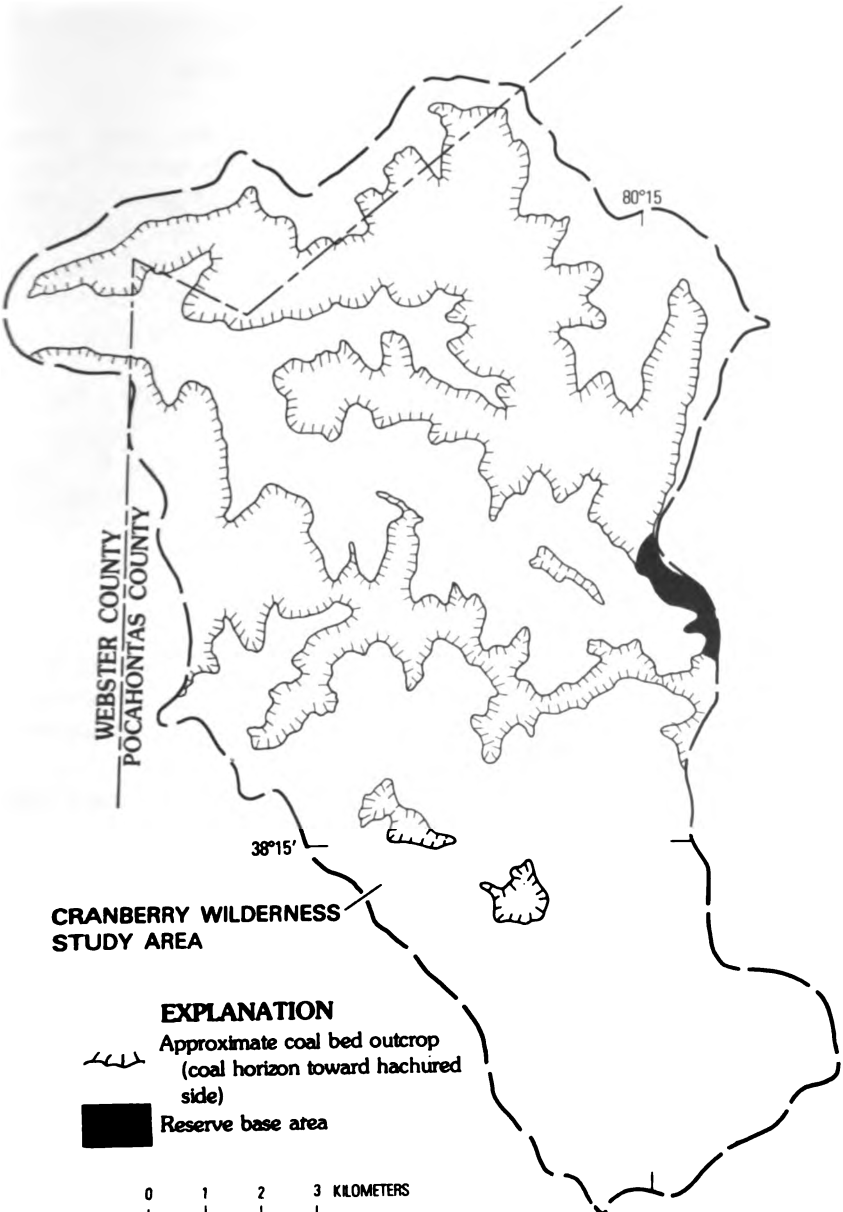



FIGURE 15.—Reserve base area, Little Raleigh (?) rider coal bed.

## PEAT RESOURCES

By Cornelia C. Cameron and Andrew E. Grosz
U.S. Geological Survey

Peat, which is partly decomposed vegetable matter that accumulated under water or in a water-saturated environment, has a wide range of physical and chemical properties. For statistical purposes, the U.S. Bureau of Mines classifies peat into three general types. Material from decomposed *Sphagnum*, *Hypnum*, or other moss groups is classified as moss peat; that from reed-sedge, shrub, and tree groups is classified as reed-sedge peat; and material so decomposed that its botanical identity is obscured and further oxidation of the material has been impeded is classified as humus peat. The American Society for Testing and Materials restricts the classification of commercial quality peat to that having an ash content not exceeding 25 percent. Ash content consists of solids remaining after dry peat has been heated at 550°C.

The peat deposits in the Cranberry Wilderness Study Area are restricted to an area of approximately 304 ha, called the Cranberry Glades, on the valley floor of Cranberry River and its principal tributary, Charles Creek. This valley floor is about 7 km long and from 0.5 to a little more than 1.0 km wide. It lies at an elevation between 1,037 m at its upper or eastern end and 1,021 m at the lower end.

Cranberry Glades includes several peat bogs that total about 46 ha—(1) Big Glade (fig. 16), (2) Long Glade, (3) Round Glade, and (4) Flag Glade.

A forest consisting of red spruce, hemlock, yellow birch, and black ash borders these glades. Shrubs in the forest include winterberry, wild raisin, rhododendron, and yew. Sphagnum and other mosses grow over much of the forest floor. The principal deposits of commercial quality reed-sedge and moss peat occur in the form of open bogs. Their dominant floral cover is sedge, grass, moss, high bush cranberry (vibernum), low shrubs, and dwarf trees.

The uniqueness of Cranberry Glades in the Southern Appalachians has stimulated study since 1898 (Core, 1955). The most extensive study was made by Darlington (1943), who conducted observations over a period of 12 years and made pace and compass traverses. He obtained his profile data from 100 holes by using a Hiller peat sampler. Cameron (1970, 1972) also made subsurface studies of the Glades using a Davis peat sampler and a Macaulay peat auger. This summary of peat resources in the Cranberry

FIGURE 16.—View of Big Glade.

Wilderness Study Area is based on previous studies, together with current sampling and mapping during the spring of 1977.

The steep-sided, flat-floored valley containing Cranberry Glades is incised in sandstone and shale. Peat appears to have accumulated on a northwest-dipping homocline. Darlington (1943) suggested lateral erosion as a cause of widening of the Cranberry River system in shale and siltstone of the Bluefield Formation (fig. 17). This lateral erosion was caused by natural damming of the Cranberry River headwaters where they come to grade on the more resistant Stony Gap(?) Sandstone Member.

Noticeable encroachment of the forest has taken place within the past 25 years and is associated with a drop of water table. Cores of the peat deposits taken during the present study show the following sequence from the bottom upward: alluvial silt, light blue-gray pond clay, peaty clay (at least 50 percent ash content), clayey peat (25 to 50 percent ash content), reed-sedge peat containing wood, and finally sphagnum-moss peat. The first peat began to form an estimated 10,000 years ago (Darlington, 1943). It formed in marshes on filled-in ponds and in depressions behind natural levees. The moss peat produced raised bogs over the marsh surfaces. Note the location of the sphagnum and reed-sedge peat deposits in the interfluves on the geologic map (fig. 17).

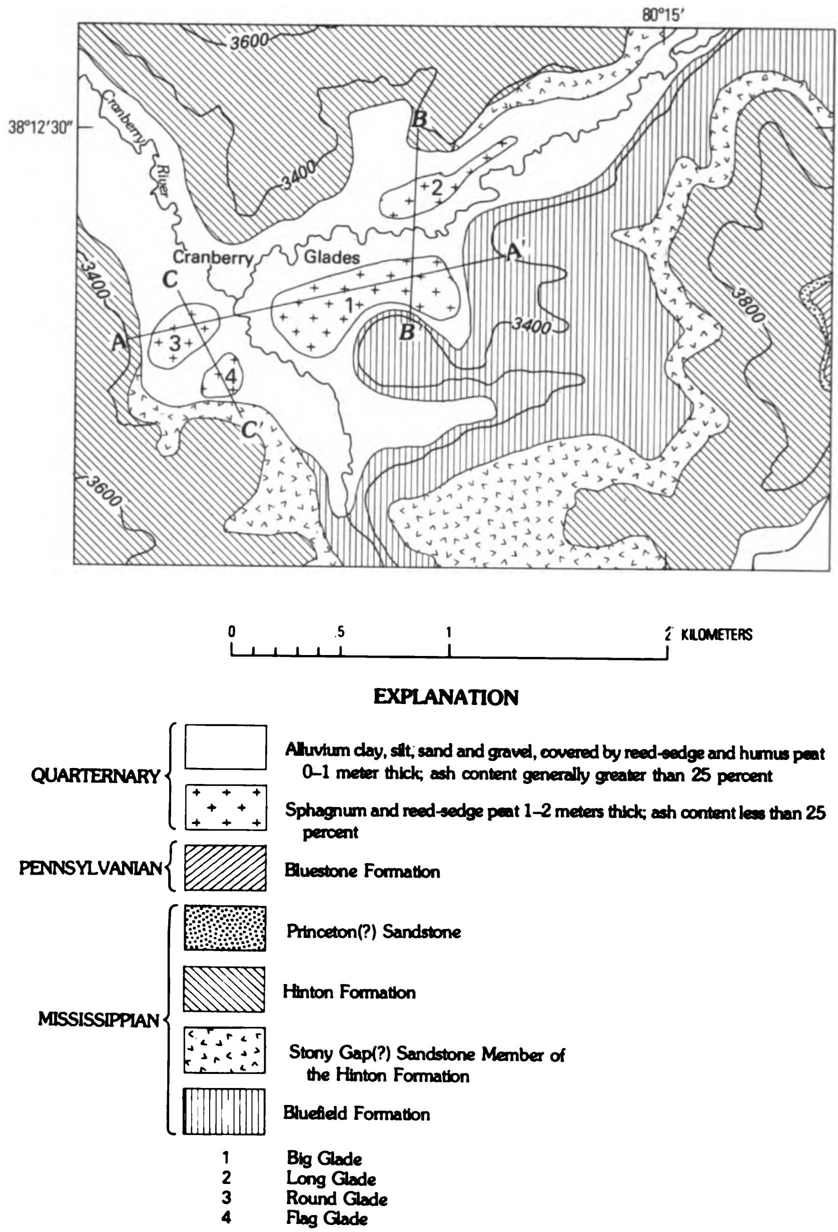



FIGURE 17.—Geologic map of the Cranberry Glades, and vicinity, Cranberry Wilderness Study Area. Points *A–A′*, *B–B′*, and *C–C′* mark locations of profiles of peat deposits shown in figure 18.

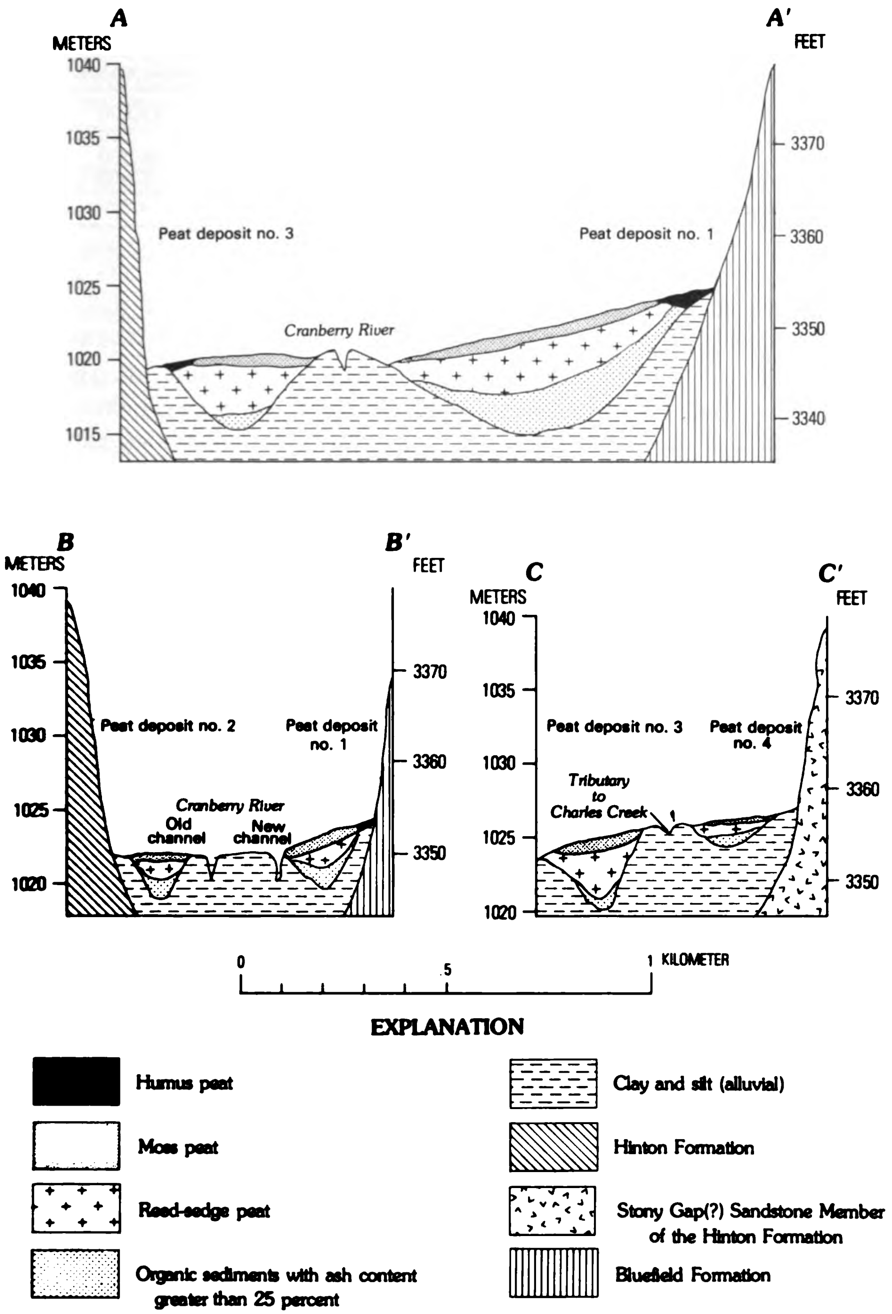



FIGURE 18.—Generalized profiles of peat deposits showing relation to drainage. Locations are shown on map (fig. 17). Deposits occupy abandoned stream channels behind natural levees in which present streams are entrenched.

TABLE 5.—*Size, thickness, and tonnages of four major peat bogs in the Cranberry Glades*

| Deposit number (see fig. 17) | Size (hectares) | Average thickness (m) | Metric tons (air-dried peat) |
|---|---|---|---|
| 1. Big Glade | 24 | 1.2 | 43,500 |
| 2. Long Glade | 8 | .6 | 7,500 |
| 3. Round Glade | 11 | 1.2 | 20,300 |
| 4. Flag Glade | 3 | .6 | 2,900 |
| Total | | | 74,200 |

The three profiles on figure 18 show the stratigraphy of the peat deposits and their positions relative to the modern stream system.

Although the reed-sedge and sphagnum peat reach maximum depths of 1 to 2.5 m in the four major bogs, average thicknesses are 0.6-1.2 m (table 5). The amount of peat in these bogs ranges from 2,900 to 43,500 metric tons and totals 74,200 metric tons of air-dried peat. One or two thousand additional tons may lie in small scattered basins in Cranberry Valley Alluvium mapped (fig. 17) as reed-sedge and humus peat 0 to 1.2 m thick, containing ash content generally greater than 25 percent. Peat deposits in the Cranberry Wilderness Study Area are too small and thin to consider exploiting commercially, at present.

Using a soil probe, the U.S. Bureau of Mines collected 6 peat samples to achieve a balanced distribution of material through the profile. Proximate analyses of these samples (table 6) show that the peat is of fuel quality and has low ash and sulfur contents and adequate heating value.

## SHALE AND CLAY

Sixteen shale and underclay samples from the Bluefield, Hinton, Bluestone, and New River Formations, and from Quaternary deposits in the study area were subjected to standard preliminary ceramic tests (table 7, pl. 2B). Tests indicate that all samples except WVC–604 and 641 are suitable for building brick. Sample WVC–606 is also considered marginally suitable for structural tile and sample 609 for floor brick. Two samples (WVC–609 and 643) expanded during the quick-firing bloating test, but only sample WVC–643 is considered suitable for lightweight aggregate in the short-firing range.

Underclay samples were analyzed for aluminum by atomic absorption (table 8). None of the tested samples showed a content high enough to be considered a source of alumina.

TABLE 6.—*Proximate analyses of peat samples, Cranberry Wilderness Study Area, W. Va.*

[Prepared by: Maynard L. Dunn, Jr., U.S. Bureau of Mines. Analyses by Department of Energy. Division of Solid Fuel Mining and Preparation, Coal Analysis (formerly U.S. Bureau of Mines, Coal Preparation and Analysis Group), Pittsburgh, Pa. Symbols used: AR, as received; MF, Moisture free; MAF, Moisture and ash free. Samples were oven dried; consequently, heating values may be high]

| Bog name and sample number | Condition of sample | Moisture | Volatile matter | Fixed carbon | Ash | Sulfur | Calorific value (Btu/lb) |
|---|---|---|---|---|---|---|---|
| Flag Glade ---- | AR | 7.8 | 51.4 | 20.9 | 19.9 | 0.4 | 7,153 |
| WVC–661 | MF | --- | 55.7 | 22.7 | 21.6 | .5 | 7,755 |
| | MAF | --- | 71.1 | 28.9 | --- | .6 | 9,894 |
| Round Glade -- | AR | 7.8 | 63.9 | 20.1 | 8.2 | .2 | 8,518 |
| WVC–662 | MF | --- | 69.4 | 21.7 | 8.9 | .2 | 9,242 |
| | MAF | --- | 76.1 | 23.9 | --- | .3 | 10,141 |
| Big Glade ----- | AR | 7.5 | 61.4 | 21.1 | 10.0 | .3 | 8,224 |
| WVC–642 | MF | --- | 66.4 | 22.8 | 10.8 | .4 | 8,892 |
| | MAF | --- | 74.4 | 25.6 | --- | .4 | 9,974 |
| WVC–644 --- | AR | 9.7 | 63.1 | 23.6 | 4.6 | .3 | 8,212 |
| | MF | --- | 69.1 | 25.8 | 5.1 | .3 | 8,994 |
| | MAF | --- | 72.8 | 27.2 | --- | .3 | 9,475 |
| WVC–666 --- | AR | 8.2 | 62.6 | 23.0 | 6.2 | .3 | 8,250 |
| | MF | --- | 68.2 | 25.1 | 6.7 | .4 | 8,983 |
| | MAF | --- | 73.1 | 26.9 | --- | .4 | 9,633 |
| Long Glade --- | AR | 7.2 | 53.1 | 18.6 | 21.1 | .2 | 7,377 |
| WVC–667 | MF | --- | 57.2 | 20.1 | 22.7 | .2 | 7,945 |
| | MAF | --- | 74.0 | 26.0 | --- | .3 | 10,275 |

Because of the abundance of shale and clay in the State, these deposits could not compete economically with more readily available material outside the study area.

## HIGH-SILICA SANDSTONE

Twelve sandstone and conglomeratic sandstone samples were taken from exposures and drill cores in the study area (pl. 2B). Analyses show that three samples have a silica ($SiO_2$) content greater than 90 percent, but all have higher percentages of aluminum (Al), iron (Fe), magnesium (Mg), and titanium (Ti) than are considered suitable for high-silica sand (table 8). Locally, some sandstones may qualify for low-quality glass sand; the great distance from markets reduces their economic potential.

## STONE

Sandstone and conglomeratic sandstone suitable for construction purposes are present in the study area. According to Reger and others (1920, p. 540), attempts to quarry the Princeton (?) Sandstone in the southeastern quarter of Webster County for building blocks were not economically successful, but they believed that the material seemed well adapted for concrete aggregate.

TABLE 7.—*Evaluation of shale and clay samples,*

[Analyses by the U.S. Bureau of Mines, Tuscaloosa Metallurgy Research Center, Tuscaloosa, or process design ]

| Sample number | Sample interval (meters) | Formation[2] | Raw properties | Temp.[3] °C |
|---|---|---|---|---|
| WVC-602 | 0.7 | Pnr | Water of plasticity: 12.7% | 1000 |
| | | | Working properties: short | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: fair | 1150 |
| | | | pH: 7.5 | 1200 |
| | | | HCl effervescence: none | 1250 |
| WVC-604 | 1.7 | Pnr | Water of plasticity: 17.4% | 1000 |
| | | | Working properties: short | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: poor | 1150 |
| | | | pH: 7.8 | 1200 |
| | | | HCl effervescence: none | 1250* |
| WVC-605 | 1.5 | Pnr | Water of plasticity: 13.4% | 1000 |
| | | | Working properties: short | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: fair | 1150 |
| | | | pH: 7.6 | 1200 |
| | | | HCl effervescence: none | 1250* |
| WVC-606 | 2.1 | Pnr | Water of plasticity: 16.2% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: fair | 1150 |
| | | | pH: 7.5 | 1200 |
| | | | HCl effervescence: none | 1250 |
| WVC-609 | 2.1 | Pnr | Water of plasticity: 14.5% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: fair | 1150 |
| | | | pH: 7.5 | 1200 |
| | | | HCl effervescence: none | 1250 |
| WVC-612 | 9.1 | Mh | Water of plasticity: 18.6% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 5.0% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 5.2 | 1200 |
| | | | HCl effervescence: none | 1250 |
| WVC-615 | 7.6 | PMb | Water of plasticity: 16.8% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 5.0% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 5.5 | 1200 |
| | | | HCl effervescence: none | 1250 |

*Cranberry Wilderness Study Area, W. Va.*[1]

Ala. All data presented are based on preliminary laboratory tests and will not suffice for plant

| Slow firing test | | | | | | |
|---|---|---|---|---|---|---|
| Munsell color | Mohs' hardness | Linear shrinkage (percent) | Absorption (percent) | Apparent porosity (percent) | Bulk density (gm/cc) | Potential use |
| 7.5 YR 8/4 | 3 | 2.5 | 13.4 | 26.3 | 1.94 | Building brick |
| 7.5 YR 8/4 | 3 | 2.5 | 13.4 | 26.1 | 1.96 | |
| 7.5 YR 7/6 | 3 | 2.5 | 11.3 | 22.9 | 2.03 | |
| 7.5 YR 7/6 | 4 | 2.5 | 9.9 | 20.1 | 2.03 | |
| 7.5 YR 7/6 | 4 | 5.0 | 9.2 | 19.1 | 2.07 | |
| 2.5 Y 7/2 | 6 | 5.0 | 3.5 | 7.9 | 2.27 | |
| 7.5 YR 8/4 | 2 | 2.5 | 16.9 | 30.4 | 1.80 | None, too soft below 1250°C |
| 5 YR 8/4 | 2 | 2.5 | 16.5 | 29.7 | 1.80 | |
| 5 YR 7/6 | 3 | 2.5 | 14.5 | 26.9 | 1.86 | |
| 5 YR 6/6 | 3 | 2.5 | 13.2 | 24.8 | 1.87 | |
| 5 YR 6/4 | 3 | 5.0 | 12.2 | 23.2 | 1.91 | |
| 10 YR 5/2 | 6 | 7.5 | 3.0 | 6.6 | 2.24 | |
| 5 YR 8/4 | 3 | 2.5 | 15.8 | 29.7 | 1.88 | Building brick |
| 5 YR 7/4 | 3 | 2.5 | 15.5 | 29.1 | 1.88 | |
| 5 YR 7/6 | 3 | 5.0 | 12.6 | 24.6 | 1.96 | |
| 5 YR 6/6 | 4 | 5.0 | 10.8 | 21.7 | 2.01 | |
| 5 YR 6/4 | 4 | 5.0 | 10.1 | 20.6 | 2.05 | |
| 2.5 YR 6/2 | 6 | 5.0 | 3.3 | 7.0 | 2.14 | |
| 7.5 YR 9/2 | 3 | 5.0 | 15.4 | 29.1 | 1.82 | Building brick |
| 7.5 YR 9/2 | 3 | 5.0 | 15.0 | 27.4 | 1.89 | Structural tile |
| 7.5 YR 8/4 | 3 | 5.0 | 12.6 | 25.0 | 1.98 | |
| 7.5 YR 8/4 | 4 | 5.0 | 10.4 | 21.4 | 2.06 | |
| 10 YR 7/4 | 4 | 5.0 | 7.0 | 14.7 | 2.09 | |
| 2.5 YR 7/2 | 5 | 5.0 | 4.8 | 10.9 | 2.24 | |
| 2.5 YR 6/4 | 3 | 5.0 | 29.0 | 49.0 | 1.69 | Building brick |
| 2.5 YR 5/4 | 4 | 5.0 | 13.7 | 27.6 | 2.01 | Floor brick |
| 2.5 YR 4/4 | 5 | 7.5 | 9.7 | 21.2 | 2.18 | |
| 2.5 YR 3/4 | 5 | 7.5 | 7.5 | 16.7 | 2.23 | |
| 10 R 4/2 | 6 | 10.0 | 5.5 | 12.7 | 2.33 | |
| 10 R 3/1 | 7 | 10.0 | 1.4 | 3.4 | 2.38 | |
| 2.5 YR 6/8 | 3 | 5.0 | 19.7 | 37.0 | 1.88 | Building brick |
| 2.5 YR 5/8 | 4 | 7.5 | 8.2 | 17.6 | 2.16 | |
| 2.5 YR 5/6 | 5 | 10.0 | 3.9 | 9.2 | 2.37 | |
| 2.5 YR 4/6 | 5 | 10.0 | 2.4 | 5.7 | 2.42 | |
| - | - | Melted | - | - | - | |
| - | - | - | - | - | - | |
| 2.5 YR 6/8 | 3 | 5.0 | 15.8 | 26.2 | 1.66 | Do. |
| 2.5 YR 6/8 | 3 | 5.0 | 11.4 | 23.4 | 2.06 | |
| 2.5 YR 5/8 | 4 | 7.5 | 7.7 | 17.1 | 2.22 | |
| 2.5 YR 4/8 | 5 | 7.5 | 5.4 | 12.4 | 2.29 | |
| 2.5 YR 4/6 | 6 | 10.0 | 4.0 | 9.4 | 2.33 | |
| 2.5 YR 3/2 | 7 | 10.0 | 2.1 | 5.0 | 2.33 | |

TABLE 7.—*Evaluation of shale and clay samples,*

| Sample number | Sample interval (meters) | Formation[2/] | Raw properties | Temp.[3/] °C |
|---|---|---|---|---|
| WVC-618 | 0.1 | Pnr | Water of plasticity: 17.8% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 5.6 | 1200 |
| | | | HCl effervescence: none | 1250 |
| WVC-636 | 3.0 | PMb | Water of plasticity: 15.1% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 6.2 | 1200 |
| | | | HCl effervescence: slight | 1250 |
| WVC-639 | 6.1 | PMb | Water of plasticity: 14.0% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 6.7 | 1200 |
| | | | HCl effervescence: slight | 1250 |
| WVC-641 | 6.1 | PMb | Water of plasticity: 13.0% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 7.7 | 1200 |
| | | | HCl effervescence: high | 1250 |
| WVC-643 | 0.3 | Q | Water of plasticity: 23.8% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 4.9 | 1200 |
| | | | HCl effervescence: none | 1250 |
| WVC-645 | 2.4 | PMb | Water of plasticity: 13.6% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 0% | 1100 |
| | | | Dry strength: fair | 1150 |
| | | | pH: 6.6 | 1200* |
| | | | HCl effervescence: slight | 1250 |
| WVC-654 | 0.8 | Pnr | Water of plasticity: 15.7 | 1000 |
| | | | Working properties: short | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: poor | 1150 |
| | | | pH: 5.7 | 1200 |
| | | | HCl effervescence: none | 1250 |

*Cranberry Wilderness Study Area, W. Va.*[1]—Continued

| Slow firing test | | | | | | |
|---|---|---|---|---|---|---|
| Munsell color | Mohs' hardness | Linear shrinkage (percent) | Absorption (percent) | Apparent porosity (percent) | Bulk density (gm/cc) | Potential use |
| 5 YR 8/4 | 3 | 2.5 | 13.4 | 25.8 | 1.93 | Building brick |
| 5 YR 8/4 | 3 | 5.0 | 11.9 | 24.7 | 2.08 | |
| 5 YR 7/6 | 5 | 5.0 | 7.2 | 15.5 | 2.15 | |
| 5 YR 6/6 | 6 | 7.5 | 4.9 | 10.9 | 2.22 | |
| 2.5 YR 5/4 | 6.5 | 10.0 | 2.4 | 5.5 | 2.28 | |
| - | - | Melted | - | - | - | |
| 2.5 YR 6/8 | 3 | 2.5 | 16.6 | 30.5 | 1.83 | Do. |
| 2.5 YR 5/8 | 3 | 5.0 | 11.9 | 24.2 | 2.03 | |
| 2.5 YR 5/6 | 4 | 5.0 | 7.7 | 16.7 | 2.18 | |
| 2.5 YR 4/6 | 5 | 7.5 | 5.0 | 11.2 | 2.26 | |
| 2.5 YR 3/4 | 6 | 10.0 | 2.7 | 6.3 | 2.31 | |
| - | - | Melted | - | - | - | |
| 2.5 YR 6/8 | 3 | 2.5 | 16.6 | 30.5 | 1.83 | Do. |
| 2.5 YR 5/8 | 4 | 5.0 | 11.9 | 24.2 | 2.03 | |
| 2.5 YR 4/6 | 4 | 5.0 | 7.7 | 16.7 | 2.18 | |
| 2.5 YR 4/4 | 5 | 5.0 | 5.0 | 11.2 | 2.26 | |
| 10 R 4/2 | 6 | 5.0 | 2.7 | 6.3 | 2.31 | |
| - | - | Melted | - | - | - | |
| 2.5 YR 5/8 | 3 | 2.5 | 10.7 | 22.1 | 2.06 | None, short firing range |
| 2.5 YR 5/8 | 3 | 2.5 | 10.1 | 21.6 | 2.13 | |
| 2.5 YR 4/6 | 4 | 5.0 | 5.0 | 11.2 | 2.26 | |
| 2.5 YR 3/4 | 6 | 5.0 | 1.8 | 4.2 | 2.34 | |
| - | - | Melted | - | - | - | |
| - | - | - | - | - | - | |
| 7.5 YR 8/6 | 3 | 5.0 | 18.7 | 33.1 | 1.77 | Building brick |
| 7.5 YR 8/6 | 3 | 5.0 | 18.1 | 32.2 | 1.78 | |
| 5 YR 6/8 | 4 | 7.5 | 7.4 | 15.8 | 2.12 | |
| 5 YR 5/6 | 5 | 7.5 | 4.7 | 10.3 | 2.19 | |
| 5 YR 5/4 | 6 | 10.0 | 2.6 | 5.8 | 2.26 | |
| - | - | Expanded | - | - | - | |
| 2.5 YR 6/8 | 3 | 2.5 | 15.6 | 29.5 | 1.89 | Do. |
| 2.5 YR 6/8 | 3 | 5.0 | 15.3 | 29.2 | 1.91 | |
| 2.5 YR 5/6 | 4 | 5.0 | 11.3 | 22.7 | 2.01 | |
| 2.5 YR 4/4 | 5 | 5.0 | 6.6 | 14.1 | 2.15 | |
| 2.5 YR 3/2 | 6 | 7.5 | 1.1 | 2.6 | 2.29 | |
| - | - | Melted | - | - | - | |
| 5 YR 7/6 | 3 | 2.5 | 14.2 | 27.4 | 1.93 | Do. |
| 5 YR 7/6 | 3 | 2.5 | 13.7 | 26.6 | 1.95 | |
| 2.5 YR 6/8 | 4 | 5.0 | 7.3 | 15.8 | 2.17 | |
| 2.5 YR 5/8 | 5 | 5.0 | 6.2 | 13.6 | 2.21 | |
| 2.5 YR 5/4 | 6 | 7.5 | 4.3 | 9.8 | 2.26 | |
| - | - | Melted | - | - | - | |

TABLE 7.—*Evaluation of shale and clay samples,*

| Sample number | Sample interval (meters) | Formation 2/ | Raw properties | Temp. 3/ °C |
|---|---|---|---|---|
| WVC-664 | 2.4 | PMb | Water of plasticity: 17.0% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 5.0% | 1100 |
| | | | Dry strength: fair | 1150 |
| | | | pH: 7.0 | 1200 |
| | | | HCl effervescence: slight | 1250 |
| WVC-668 | 1.8 | Q | Water of plasticity: 24.9% | 1000 |
| | | | Working properties: plastic | 1050 |
| | | | Drying shrinkage: 2.5% | 1100 |
| | | | Dry strength: good | 1150 |
| | | | pH: 4.9 | 1200 |
| | | | HCl effervescence: none | 1250* |

Preliminary

| Sample number | Temp. °C | Absorption (percent) | Bulk density (gm/cc) | Bulk density (lb/ft³) |
|---|---|---|---|---|
| WVC-609 | 1000 | 10.4 | 1.75 | 109.4 |
| | 1050 | 10.5 | 1.65 | 103.2 |
| | 1100 | 10.2 | 1.59 | 99.2 |
| | 1150 | 24.9 | 0.75 | 46.6 |
| WVC-643 | 1100 | 7.8 | 1.85 | 115.3 |
| | 1150 | 7.3 | 1.79 | 111.4 |
| | 1200 | 6.1 | 1.56 | 97.2 |
| | 1250 | 7.1 | 0.86 | 53.7 |

1/ Analyses by the U.S. Bureau of Mines, Tuscaloosa Metallurgy Research Center,
laboratory tests and will not suffice for plant or process design.
2/ Pnr--New River Formation; PMb--Bluestone Formation; Mh--Hinton Formation;
3/ Asterisk denotes abrupt vitrification prior to temperature noted.
4/ All samples except WVC-609 and 643 showed negative preliminary bloating

602 - Drill core, medium gray underclay, about 228 meters below surface.
604 - Drill core, medium dark gray flinty underclay, about 92 meters below surface.
605 - Drill core, medium gray underclay, about 208 meters below surface.
606 - Drill core, light gray underclay, about 194 meters below surface.
609 - Outcrop, black carbonaceous shale.
612 - Roadcut, grayish-red shale.
615 - Outcrop, grayish-red shale.
618 - Outcrop, dark gray underclay.

*Cranberry Wilderness Study Area, W. Va.*[1]—Continued

| Slow firing test | | | | | | |
|---|---|---|---|---|---|---|
| Munsell color | Mohs' hardness | Linear shrinkage (percent) | Absorption (percent) | Apparent porosity (percent) | Bulk density (gm/cc) | Potential use |
| 2.5 YR 6/8 | 3 | 5.0 | 12.2 | 24.7 | 2.02 | Building brick |
| 2.5 YR 6/8 | 3 | 5.0 | 11.6 | 23.7 | 2.04 | .. |
| 2.5 YR 5/6 | 4 | 7.5 | 6.3 | 14.0 | 2.21 | |
| 2.5 YR 4/6 | 5 | 10.0 | 5.8 | 12.7 | 2.21 | |
| 10 R 4/4 | 6 | 10.0 | 4.0 | 9.0 | 2.25 | |
| - | - | Melted | - | - | - | |
| 5 YR 7/8 | 3 | 5.0 | 29.3 | 43.6 | 1.49 | Do. |
| 5 YR 7/8 | 3 | 5.0 | 20.5 | 34.8 | 1.70 | |
| 2.5 YR 6/8 | 4 | 7.5 | 18.7 | 32.0 | 1.71 | |
| 2.5 YR 5/8 | 4 | 7.5 | 11.6 | 22.4 | 1.94 | |
| 2.5 YR 5/6 | 4 | 10.0 | 8.6 | 17.2 | 2.00 | |
| 10 YR 4/2 | 6 | 10.0 | 1.3 | 2.7 | 2.10 | |

bloating test[4/]

| Remarks | Potential use |
|---|---|
| Slight expansion | Not suitable for lightweight aggregate |
| Slight expansion | |
| Good pore structure (sticky) | |
| Some large pores (sticky) | |
| Slight expansion | Marginal for lightweight aggregate |
| Good pore structure | |
| Good pore structure | |
| Some large pores | |

Tuscaloosa, Alabama. All data presented are based on preliminary

Q--Quaternary.

test results.

636 - Outcrop, grayish-red shale.
639 - Roadcut, grayish-red and greenish-gray shale.
641 - Roadcut, grayish-red silty shale.
643 - Auger core, light gray underclay, below peat.
645 - Outcrop, medium gray shale.
654 - Roadcut, dark gray underclay.
664 - Roadcut, grayish-red and greenish-gray shale.
668 - Outcrop, light reddish-gray to light gray underclay, below peat.

TABLE 8.—*Analyses of rock samples from*

[Analyses performed by U.S. Bureau of Mines, Reno Metallurgy Research Center, Reno, Nev. spectrographically and detected but less than the lower limit(s) of determination (unless B (0.01–0.03), Be (0.001), Bi (0.06–0.5), Cd (0.001–0.004), Co (0.001–0.003), Cu (0.001), (0.001–0.003), P (0.2–0.5), Pb (0.03–0.1), Pd (0.001), Pt (0.003–0.009), Sb (0.03– V (0.001–0.004), W (0.04–0.1), Y (0.005–0.01), Zr (0.002–0.009). All numbers given in possible error of plus or minus 100 percent of reported concentration is assumed. Symbols and lower limits of determination may vary because of interference corrections ]

| Sample number | General spectrographic analyses (percent) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Al | Ba | Ca | Cr | Fe | K | Li | Mg | Mn | Sr | Ti |
| WVC-601 | 2 | <0.002 | <0.1 | <0.001 | 3 | <2 | <0.001 | 0.1 | 0.02 | <0.001 | 0.5 |
| WVC-602 | 12 | .04 | <.1 | .005 | 3 | 3 | .007 | 1 | .01 | .001 | 2 |
| WVC-603 | .8 | <.002 | <.1 | <.002 | 4 | <3 | <.001 | .04 | .01 | <.001 | .2 |
| WVC-604 | 7 | .01 | <.1 | .003 | 3 | 4 | .006 | 2 | .03 | <.001 | 1 |
| WVC-605 | 8 | .02 | <.1 | .005 | 3 | 4 | .006 | 2 | .04 | .001 | .9 |
| WVC-606 | 14 | .03 | <.1 | .004 | 4 | <3 | .01 | 1 | .04 | .001 | 2 |
| WVC-609 | 9 | .03 | <.1 | <.004 | 13 | 4 | <.004 | .9 | .3 | <.001 | 1 |
| WVC-612 | 11 | .03 | <.2 | <.002 | 6 | 3 | <.002 | 3 | .03 | .004 | 2 |
| WVC-615 | 14 | .02 | .2 | .005 | 7 | 3 | .008 | 2 | .06 | .002 | 1 |
| WVC-618 | 13 | .03 | <.1 | .002 | 3 | 6 | .008 | 2 | .02 | .002 | 1 |
| WVC-628 | 6 | .008 | 3 | <.002 | 4 | <2 | <.002 | 1 | .2 | .002 | .7 |
| WVC-629 | 3 | <.002 | <.1 | <.001 | 3 | <2 | <.001 | .2 | .01 | <.001 | .6 |
| WVC-632 | 8 | .01 | <.1 | <.001 | 5 | <2 | <.001 | 1 | .03 | <.001 | 1 |
| WVC-633 2/ | 6 | .004 | <.1 | <.001 | 4 | <2 | <.001 | 1 | .03 | <.001 | .7 |
| WVC-636 | 8 | .02 | .3 | <.001 | 5 | 3 | .003 | 3 | .05 | <.001 | 1 |
| WVC-638 | 1 | <.002 | 3 | <.001 | 5 | <2 | <.001 | .9 | .1 | <.001 | .3 |
| WVC-639 | 9 | .02 | 1 | <.004 | 7 | <6 | <.004 | 2 | .07 | <.001 | 2 |
| WVC-640 | 8 | .02 | 1 | <.001 | 4 | <2 | <.001 | 1 | .06 | .001 | .9 |
| WVC-641 | 13 | .02 | 2 | <.004 | 7 | <6 | <.004 | 2 | .07 | .005 | 3 |
| WVC-643 | 7 | .02 | <.1 | .003 | 3 | 3 | .001 | 2 | .02 | .004 | .9 |
| WVC-645 | 9 | .02 | 2 | .002 | 5 | 3 | .002 | 2 | .09 | .002 | 1 |
| WVC-646 | 1 | <.002 | <.1 | <.001 | 5 | 2 | <.002 | .02 | .02 | <.001 | .4 |
| WVC-647 | .6 | <.002 | <.1 | <.001 | 1 | <2 | <.001 | <.002 | .004 | <.001 | <.3 |
| WVC-654 | 12 | .06 | <.3 | <.004 | 8 | 6 | <.004 | 2 | .07 | .002 | 4 |
| WVC-655 3/ | .7 | <.004 | <.2 | <.002 | 4 | 3 | <.002 | .04 | .06 | <.001 | <.3 |
| WVC-664 | 6 | .02 | .4 | .004 | 4 | 3 | .007 | 2 | .05 | .002 | 1 |
| WVC-668 | 5 | .02 | <.1 | .003 | 3 | 2 | .004 | 2 | .02 | .002 | .9 |
| WVC-671 4/ | .3 | <.007 | <.3 | <.004 | 3 | <6 | <.004 | .02 | .04 | <.001 | <.5 |
| WVC-673 | 1 | <.002 | 3 | <.001 | 3 | <2 | <.001 | .7 | .1 | .007 | <.2 |
| WVC-674 | <.2 | <.002 | <.1 | .001 | 2 | <2 | .002 | <.002 | .01 | <.001 | <.2 |
| WVC-675 | 8 | .01 | <.1 | .003 | 4 | <2 | <.001 | 1 | .07 | .003 | .7 |

1/ Calculated value from elemental determination.
2/ Contains .02 percent Zr by spectrographic analysis.
3/ Contains .006 percent Ag by spectrographic analysis.
4/ Contains .006 percent Cu by spectrographic analysis.

*the Cranberry Wilderness Study Area, W. Va.*

**Samples are random chips every 2-10 cm through interval noted. Elements tested for otherwise noted in footnote) include: Ag (0.002–0.005), As (0.006–0.02), Au (0.001–0.004), Ga (0.001–0.002), La (0.01–0.03), Mo (0.002–0.007), Na (1–6), Nb (0.002–0.005), Ni 0.1), Sc (0.001–0.002), Se (0.9–3), Sn (0.002–0.01), Ta (0.03–0.1), Te (0.01–0.2), percent. Si occurs in all samples greater than the upper detection limit (20–40 percent). A used: <, detected but less than lower limit of determination; —, not looked for. The upper**

| | Atomic absorption[1/] (percent) | | Neutron activation[1/] (percent) | Radiometric[1/] (percent) | Sample interval | |
|---|---|---|---|---|---|---|
| Zn | $Al_2O_3$ | $Fe_2O_3$ | $SiO_2$ | $U_3O_8$ | (meters) | Sample description |
| <0.001 | -- | -- | 89 | 0.001 | 11.7 | Sandstone |
| <.001 | 17 | 2.8 | 70.4 | -- | .7 | Underclay |
| <.001 | 1.2 | 1.4 | 96.2 | .001 | 3.4 | Sandstone |
| <.001 | 12.4 | 3.2 | 72.9 | -- | 1.6 | Underclay |
| <.001 | 18 | 4.3 | 63.5 | -- | 1.5 | Do. |
| <.001 | 19.8 | 4.7 | 57.6 | -- | 2.1 | Underclay |
| <.001 | -- | -- | -- | .002 | 2.1 | Shale-carbonaceous |
| .001 | 18 | 7.7 | -- | -- | 9.1 | Shale |
| <.001 | 18.7 | 7.7 | -- | -- | 7.6 | Do. |
| <.001 | -- | -- | -- | -- | .1 | Underclay |
| <.001 | -- | -- | -- | .001 | 3.6 | Sandstone |
| .001 | -- | -- | -- | .001 | 4.2 | Do. |
| <.001 | -- | -- | -- | -- | 3.6 | Do. |
| <.001 | -- | -- | -- | -- | 7.6 | Do. |
| <.001 | 16.1 | 5.6 | -- | -- | 3 | Shale |
| <.001 | 3.7 | 5.8 | -- | .001 | 4.2 | Conglomerate |
| <.001 | 16.7 | 8.4 | -- | -- | 7.6 | Shale |
| <.001 | -- | -- | -- | -- | 8.8 | Sandstone |
| <.001 | -- | -- | -- | -- | 6.1 | Shale |
| .01 | 16.1 | 3.7 | -- | -- | .3 | Underclay |
| .003 | -- | -- | -- | -- | 2.4 | Shale |
| <.001 | -- | -- | -- | -- | 4.6 | Sandstone |
| <.001 | 1 | .95 | -- | .001 | 7.9 | Sandstone/conglomerate |
| <.001 | 21.8 | 5.3 | 60.6 | .001 | .8 | Underclay |
| <.001 | -- | -- | -- | .001 | 1.5 | Sandstone/conglomerate |
| .005 | 16.6 | 7.7 | -- | -- | 2.4 | Shale |
| .003 | 12.4 | 3.7 | 76.3 | -- | 1.8 | Underclay |
| <.001 | .74 | 2.3 | 96.2 | .001 | 1.2 | Sandstone/conglomerate |
| .008 | 2.7 | 2.3 | 81.1 | .001 | 1.2 | Conglomerate |
| .002 | .42 | 1 | 97.6 | -- | 1.5 | Sandstone/conglomerate |
| .004 | 11.3 | 4.7 | 85.6 | -- | .4 | Underclay |

The possibility of commercial development of any of the sandstone units in the study area is low because stone is abundant throughout the State (Price, 1952, p. 10) and the study area is not readily accessible.

The Greenbrier Limestone of Mississippian age crops out southeast of the study area and is mined about 7 km to the southeast. This unit is not exposed in the study area, but was found in an oil and gas test well at a depth of 451 m in the western part of the study area. Because of this depth below the surface and abundance of limestone to the south and southeast, the Greenbrier Limestone is not considered an economic mineral resource in the study area.

## OIL AND GAS POTENTIAL

By William J. Perry, Jr.
U.S. Geological Survey

Exploration drilling (table 9) suggests a remote chance for gas, but virtually no chance for oil in and near the Cranberry Wilderness Study Area.

Only one exploratory well, Pocahontas No. 8 (table 9), has been drilled within the study area (fig. 19). This well was drilled to a depth of 1,389 m and bottomed in Upper Devonian beds. No shows of oil or gas were reported. In a second exploratory well (Webster No. 2), drilled 7 km west of the western tip of the study area, shows of gas in Lower Mississippian sandstones were found, as well as a show in the overlying Greenbrier Limestone. This well lies on the crest of the north-northeast trending Webster Springs anticline, which does not cross the wilderness area (fig. 19). The gas on the anticline was probably structurally trapped, but was not present in sufficient quantities to warrant production. The closest current gas production is in western Webster County, approximately 19 km to the northwest. A very old well, Pocahontas Land Company No. 1 (Poca-'O', fig. 19 and table 9), was drilled 2 km east of the study area. Price and Reger (1929, p. 103–104) questioned the show of oil reported in the lower part of the Pocono Sandstone, in this hole. No shows of oil have been subsequently reported in wells in the area during the succeeding 40 years of oil and gas exploration, and furthermore, no oil discovery is expected in this area because of the high thermal maturity of the rock.

Shows of gas have been found in the Huntersville Chert (Middle Devonian) and underlying Oriskany Sandstone (Lower Devonian)

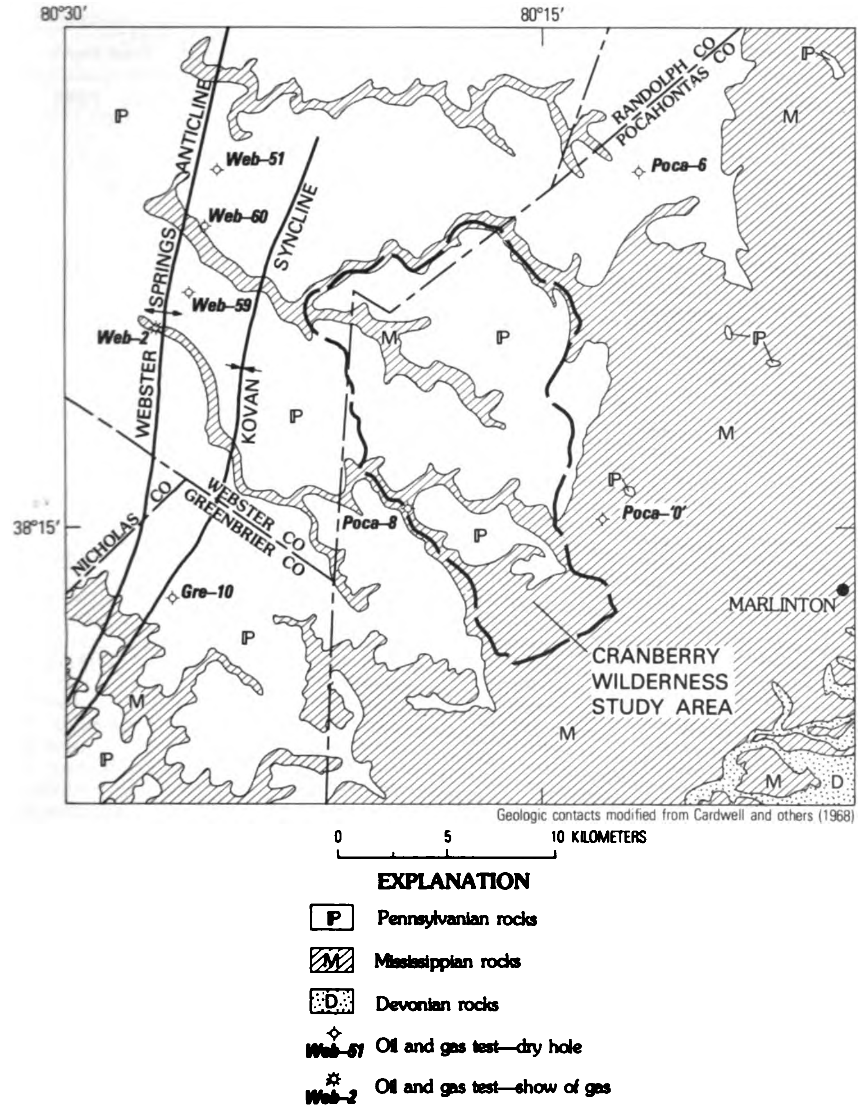



**Figure 19.**—Generalized geologic map of the Cranberry Wilderness Study Area and surrounding area.

in only two deeper wells west of the study area, Webster No. 59 and No. 60. Natural gas may be present in the "Benson" or other Upper Devonian sands, but none has been found to date. These formations are unexplored under the study area, but, on the basis of nearby dry holes, probably lack sufficient porosity to warrant

TABLE 9.—*Test wells drilled for oil and*

| County and permit no. | Operator—leasee | Elevation (m) | Total Depth (m) |
| --- | --- | --- | --- |
| Greenbrier 10 | Columbian Carbon-Cherry River Boom and Lumber Co. No. 1 (GW-1247) | 879 | 1423 |
| Pocahontas 0 (No permit number) Source: Price (1929, p. 103–104) | Pocahontas Coal and Land Co. No. 1 | 1033 | 924 |
| Pocahontas 6 | Logan Gas Development Co.-Cherry Boom and Lumber Co. No. 1 | 1046 | 1373 |
| Pocahontas 8 | Columbian Carbon-Gauley Co. No. 4 (GW-1269) | 978 | 1389 |
| Webster 2 | Hope Natural Gas Co.-W. Va. & Pittsburgh R. R. Co. No. 9227 | 768 | 1946 |
| Webster 51 | Columbian Carbon-Gauley Co. No. 3 (GW-1267) | 823 | 1274 |
| Webster 59 | Consolidated Gas Supply—Mid-Allegheny & W. Va. and Pittsburgh R. R. Co. No. 11,300 | 1095 | 2542 |
| Webster 60 | Consolidated Gas-W. Va. and Pittsburgh R. R. Co. No. 11,431 | 828 | 2221 |

*gas near Cranberry Wilderness Study Area, W. Va.*

| Lithologic zones or formations (depths in meters) | | Remarks |
|---|---|---|
| "Big Lime" (Greenbrier Limestone) | 492–626 | Dry, slight show of gas at 514 m. |
| Sandstone | 633–638 | |
| "Broken" sandstone (with shale) | 638–639 | Show gas at 1383.5 m in Benson. |
| Red beds | 774–775 | |
| Benson sandstone | 1,373–1,385 | |
| Greenbrier Limestone | 185–351 | Dry, oil show (?) in sandstones of lower part of Pocono. |
| Pocono Sandstone | 351–446 | |
| Hampshire Formation | 446–712 | |
| "Chemung Series" | 712–924 Total Depth | |
| | | |
| "Big Lime" (Greenbrier Limestone) | 367–444 | Dry, saltwater. |
| Red beds | 444–446 | |
| Sandstone | 461–469 | |
| Red beds | 675–767 | |
| Sandstone | 1,117–1,177 | |
| Red beds | 365–369 | Dry, saltwater at 501 m. |
| "Big Lime" | 451–589 | |
| Red sandstone | 589–592 | |
| Red beds | 592–595 | |
| Chiefly red beds | 13–232 | Show gas at 291 m. |
| "Big Lime" | 239–419 | Saltwater at 299 m. |
| Red beds | 419–423 | Saltwater at 341.4 m. |
| Hard sandstone | 438–450 | Show gas at 444.4 m. |
| Sandstone | 636–649 | Show gas at 645 m. |
| Hard sandstone | 701–711 | Show gas at 728 m. |
| Sandstone | 722–728 | Gas 773 m. |
| "Big Lime" | 371–457 | Dry, gas show at 457 m. |
| Sandstone | 457–474 | Saltwater at 595.6 m. |
| "Broken" sandstone | 474–492 | Saltwater at 969 m in "gritty lime". |
| Sand | 523–537 | |
| Sand | 566–613 | |
| Sand | 629–692 | |
| "Big Lime" | | |
| Tully equivalent | 2,422–2,426 | Dry, shows of gas in chert and Oriskany. |
| Huntersville Chert | 2,447–2,495 | |
| Oriskany Sandstone | 2,495–2,527 | |
| Helderberg Group | 2,527–2,542 | |
| "Lime and shells" | 386–459 | Dry, show of gas in chert. |
| "Big Lime" (?) | 459–492 | |
| Red beds | 492–634 | |
| Sandstone and shale | 1,215–2,153 | |
| Huntersville Chert and Onondaga Limestone | 2,171–2,215 | |
| Oriskany Sandstone | 2,215–2,221 | |

deeper exploration. Natural gas has been found in Lower Mississippian rocks to the west, but probably does not extend as far east as the Cranberry Wilderness Study Area on the basis of results of Pocahontas No. 8.

## GEOCHEMICAL SURVEY

By FRANK G. LESURE
U.S. GEOLOGICAL SURVEY

Reconnaissance geochemical sampling of the Cranberry Wilderness Study Area was done to find indistinct or unexposed mineral deposits that might be recognized by their geochemical halos. No metallic deposits have been reported in the study area, and none were found during the reconnaissance geologic mapping. The geochemical samples consist of 104 stream-sediment and 100 rock and mineral samples (pl. 2*C*).

Most small drainage basins within the study area and some adjacent to it were sampled by collecting the finest sediment possible. The samples were dried and sieved in the laboratory; the minus 80-mesh (0.177 mm) fraction was used for analyses.

The rock samples are representative of the major rock types exposed in the area. The freshest samples are from cores from four diamond-drill holes in the northwestern part of the area (pl. 2*C*). Other rock samples are from road cuts, coal prospects, and natural outcrops. Samples are mostly composites of small chips taken from a single rock unit.

All stream-sediment and rock samples were analyzed by semiquantitative emission spectrographic methods for 30 elements and chemically for zinc. Equivalent uranium (eU) was determined instrumentally by total gamma count. The analytical data are summarized in table 10, and the complete data are given in Motooka and others, 1978.

Only normal background values of elements tested were found in most of the rock and stream-sediment samples. No metallic mineral deposits of economic importance are known in rocks of these formations in the surrounding area. An extensive sampling of similar rocks in the same general stratigraphic sequence along the New River from Hinton to Gauley Bridge, W. Va., produced similar analytical results (Lesure and Whitlow, 1977).

A few samples of rock contain high values for some elements. One sample of green mudstone (WVC–139), from a layer 0.3 m thick enclosed in a thicker unit of red mudstone, contains 300 ppm copper and 2 ppm silver. The combination of Ag and Cu is a

TABLE 10.—*Range and median values for 25 elements in rock and stream sediment samples from the Cranberry Wilderness Study Area, Webster and Pocahontas Counties, W. Va.*

[All analyses are by J. M. Motooka using semiquantitative spectrographic methods except zinc, which is by J. D. Sharkey and J. R. Groves using atomic absorption methods and equivalent uranium (eU), which is by J. C. Negri using instrumental methods. Spectrographic analyses are reported to the nearest number in the series 1, 1.5, 2, 3, 5, 7, and 10, which represent approximate midpoints of group data on a geometric scale. The assigned groups for the series will include the quantitative value about 30 percent of the time. Letter symbols: L, detected but below limit of determination (value shown in parenthesis after element symbol); N, not detected; G, greater than. Elements looked for but not found and their lower limits of determination: As(200), Au(20), Bi(10), Cd(20), Sb(100), and W(50)]

| Elements | | Sandstone (59 samples) | | | | Shale (39 samples) | | | | Stream sediments (104 samples) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | High | Median | Average in sandstone [1,2] | Low | High | Median | Average in shale [2] | Low | High | Median |
| **Percent** | | | | | | | | | | | | |
| Ca | (0.05) | N | 10 | 0.05 | 3.9 | L | 15 | 0.2 | 2.21 | L | 0.3 | L |
| Fe | (0.05) | 0.05 | 20 | 2 | .98 | 1.5 | 10 | 3 | 4.72 | 1 | 10 | 3 |
| Mg | (0.02) | .02 | 1.5 | .3 | .7 | .5 | 1.5 | 1.0 | 1.5 | .1 | 1.0 | .2 |
| Ti | (0.002) | .07 | 1.0 | .3 | .15 | .5 | .7 | .5 | .46 | .2 | .7 | .5 |
| **Parts per million** | | | | | | | | | | | | |
| Ag | (0.5) | N | N | N | [3] 0.0X | N | 2 | N | 0.07 | N | N | N |
| B | (10) | 10 | 150 | 30 | 20–30 | 70 | 150 | 100 | 100 | 50 | 150 | 100 |
| Ba | (20) | 70 | 1,500 | 200 | 300 | 150 | G 5,000 | 300 | 500 | 150 | 700 | 200 |
| Be | (1) | N | 3 | 1 | 2 | 1 | 3 | 3 | 3 | L | 7 | 2 |
| Co | (5) | N | 30 | 10 | .3 | 7 | 30 | 20 | 19 | N | 70 | 15 |
| Cr | (10) | L | 150 | 20 | 10–20 | 50 | 100 | 70 | 90 | 15 | 100 | 50 |
| Cu | (5) | N | 50 | 5 | 10–20 | 5 | 300 | 30 | 45 | L | 30 | 15 |
| La | (20) | N | 100 | N | 30 | N | 50 | 30 | 92 | N | 150 | 20 |
| Mn | (10) | 10 | 3,000 | 500 | 500 | 150 | 5,000 | 700 | 850 | 70 | G 5,000 | 1,000 |
| Mo | (5) | N | 15 | N | .2 | N | N | N | 2.6 | N | N | N |
| Nb | (20) | N | 20 | N | [3] .0X | L | L | L | 11 | L | 20 | L |
| Ni | (5) | N | 70 | 15 | 2 | 20 | 70 | 50 | 68 | N | 70 | 15 |
| Pb | (10) | N | 70 | N | 9 | N | 50 | 20 | 20 | N | 30 | 10 |
| Sc | (5) | N | 15 | 5 | 1 | 7 | 15 | 15 | 13 | N | 15 | 10 |
| Sn | (10) | N | N | N | [3] .X | N | N | N | 6 | N | 15 | N |
| Sr | (100) | N | 150 | N | 20 | N | 300 | L | 300 | N | 200 | N |
| V | (10) | 15 | 200 | 50 | 10–20 | 50 | 200 | 150 | 130 | 30 | 150 | 100 |
| Y | (10) | L | 70 | 20 | 40 | 20 | 50 | 30 | 26 | 15 | 50 | 20 |
| Zn | (5) | 5 | 150 | 45 | 16 | 25 | 130 | 85 | 95 | 20 | 230 | 70 |
| Zr | (10) | 50 | G 1,000 | 200 | 200–250 | 150 | 1,000 | 200 | 160 | 200 | G 1,000 | 300 |
| eU | (20) | L | 30 | L | — | L | 20 | L | — | L | 20 | L |

[1] Pettijohn, F. J. (1963, p. S11).
[2] Turekian, K. K., and Wedepohl, K. H. (1961).
[3] Order of magnitude estimated by Turekian and Wedepohl (1961).

common association in some red-bed sequences (Lesure and others, 1977, p. 613). Another sample of mottled green and red mudstone (WVC–161) from a layer 5 cm thick contains more than 5,000 ppm barium. These samples suggest the possibility of stratabound metallic deposits in this red-bed sequence, but none have been found. Only a small part of the red-bed sequence is exposed along the northeastern edge of the study area and along the southern margin.

A few rocks contained minor amounts of iron sulfides, but only two samples were collected. WVC–149 is a composite of thin pyrite concretions and seams along a bedding plane in gray shale; WVC–167 is a composite of pyrite concretions and replacement of crinoid(?) fossils in micaceous sandstone. WVC–149 contains 5 ppm Ag, 1,000 ppm As, 1,000 ppm Ba, 500 ppm Co, 150 ppm Cu, 20 ppm Mo, 300 ppm Ni, and 100 ppm Pb. All are higher values than are normal in sedimentary rocks, but are not unusual for sedimentary sulfide concretions. WVC–167 has 1,500 ppm Ba and only background values for other elements. The pyrite concretions are scattered along certain bedding planes or in certain beds and do not represent enough material to be considered economically important.

## REFERENCES CITED

Abernethy, R. F., Peterson, M. J., and Gibson, F. H., 1969, Spectrochemical analyses of coal ash for trace elements: U.S. Bureau of Mines Report of Investigations 7281, 30 p.

Arkle, Thomas, Jr., and Hunter, R. G., 1957, Sandstones of West Virginia: West Virginia Geological and Economic Survey Report of Investigation 16, 58 p.

Barlow, J. A., 1974, Coal and coal mining in West Virginia: West Virginia Geologic and Economic Survey, Coal-Geology Bulletin 2, 63 p.

Cameron, C. C., 1970, Peat resources of the unglaciated uplands along the Allegheny structural front in West Virginia, Maryland, and Pennsylvania: U.S. Geological Survey Professional Paper 700–D, p. D153–D161.

——— 1972, Diagnesis and quality of peat deposits: International Peat Congress, 4th, Helsinki, Finland, Proceedings, v. 1, p. 233–245.

Cardwell, D. H., Erwin, R. B., and Woodward, H. P. (compilers), 1968, Geologic map of West Virginia: West Virginia Geological Survey, 2 sheets, scale 1:250,000.

Core, E. L., 1955, Cranberry Glades Natural Area: Wild Flower, no. 31, p. 65–81.

Darlington, H. C., 1943, Vegetation and substrata of Cranberry Glades, West Virginia: Botanical Gazette, v. 104, no. 3, p. 371–393.

Lesure, F. G., Motooka, J. M., and Weis, P. L., 1977, Exploration geochemical studies of some sandstone copper-uranium deposits, Bradford, Columbia, and Lycoming Counties, Pennsylvania: U.S. Geological Survey Journal of Research, v. 5, no. 5, p. 609–621.

Lesure, F. G., and Whitlow, J. W., 1977, Geochemical sample localities map and distribution of cobalt, chromium, and nickel, New River Gorge, area, Fayette, Raleigh, and Summers Counties, West Virginia, *in* Englund and others, 1977, Mineral Resource, geological, and geophysical maps of New River Gorge area, Fayette, Raleigh, and Summers Counties, West Virginia: U.S. Geological Survey Open-File Report 77–76, Map I.

McCue, J. B., and others, 1948, Clays of West Virginia: West Virginia Geological and Economic Survey Reports, v. 18, 234 p.

Motooka, J. M., Negri, J. C., Sharkey, J. D., and Lesure, F. G., 1978, Analyses and description of geochemical samples, Cranberry Wilderness Study Area, Pocahontas and Webster Counties, West Virginia: U.S. Geological Survey Open-File Report 78–215, 23 p.

Pettijohn, F. J., 1963, Chapter S. Chemical composition of sandstones—excluding carbonate and volcanic sands, *in* Fleischer, Michael, ed., Data of geochemistry 6th ed: U.S. Geological Survey Professional Paper 440–S, 21 p.

Price, P. H., 1952, Natural resources of West Virginia: West Virginia Geological and Economic Survey Special Publication, v. 10 supplement, 17 p.

Price, P. H., and Reger, D. B., 1929, Pocahontas County: West Virginia Geological Survey [County Reports], 531 p.

Reger, D. B., Tucker, R. C., and Buchanan, Margaret, 1920, Webster County and portion of Mingo District, Randolph County, south of Valley Fork of Elk River: West Virginia Geological Survey [County Reports], 682 p.

Swanson, V. E., Medlin, J. H., Hatch, J. R., Coleman, S. L., Wood, G. H., Jr., Woodruff, S. D., and Hildebrand, R. T., 1976, Collection, chemical analyses, and evaluation of coal samples in 1975: U.S. Geological Survey Open-File Report 76–468, 503 p.

Tallon, W. A., and Hunter, R. G., 1959, High-alumina clays of West Virginia: West Virginia Geological and Economical Survey Report of Investigations 17, 49 p.

Turekian, K. K., and Wedepohl, K. H., 1961, Distribution of the elements in some major units of the Earth's crust: Geological Society of America Bulletin, v. 72, no. 2, p. 175–191.

U.S. Bureau of Mines and U.S. Geological Survey, 1976, Coal resource classification system of the U.S. Bureau of Mines and the U.S. Geological Survey: U.S. Geological Survey Bulletin 1450–B, 7 p.

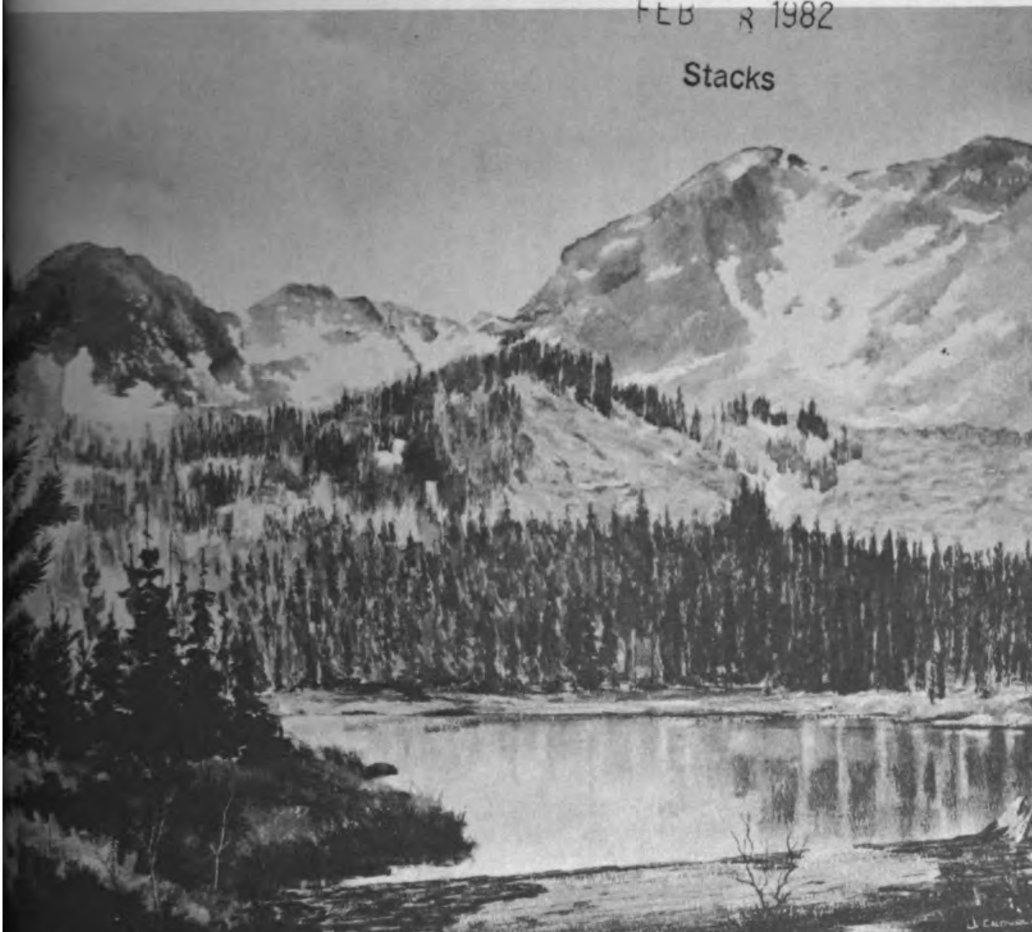
U.S. Forest Service, 1975, Coal evaluation study Moriongahela National Forest: U.S. Department of Agriculture, Forest Service, Eastern Region, unpublished report, 45 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 — 341-614/106

STUDIES RELATED TO WILDERNESS

# WILDERNESS AREAS





# SNOW MOUNTAIN, CALIFORNIA



GEOLOGICAL SURVEY BULLETIN 1495

# Mineral Resources of the Snow Mountain Wilderness Study Area, California

*By* ROBERT D. BROWN, JR., DAVID J. GRIMES, *and* REINHARD LEINZ,
U. S. GEOLOGICAL SURVEY, *and* FRANCIS E. FEDERSPIEL *and*
ANDREW M. LESZCYKOWSKY, U. S. BUREAU OF MINES

*With a section on*
INTERPRETATION OF AEROMAGNETIC DATA

*By* ANDREW GRISCOM *and* ROBERT D. BROWN JR.,
U. S. Geological Survey

STUDIES RELATED TO WILDERNESS— WILDERNESS AREAS

---

GEOLOGICAL SURVEY BULLETIN 1495

*An evaluation of the mineral potential of the area*

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1981

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *Secretary*

GEOLOGICAL SURVEY

Doyle G. Frederick, *Acting Director*

Library of Congress Cataloging in Publication Data

Mineral resources of the Snow Mountain Wilderness
study area, California.

(Studies related to wilderness--wilderness areas)
(Geological Survey bulletin ; 1495)
Bibliography: p. 46-48
Supt. of Docs. no.: I 19.3:1495
1. Mines and mineral resources--California--Snow
Mountain Wilderness study area. I. Brown,
Robert David, 1925- . II. Series: United
States. Geological Survey. Bulletin 1495.
QE75.B9 no.1495 557.3s 80-606866
[TN24.C2] [553'.09794'3]

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C. 20402

## STUDIES RELATED TO WILDERNESS

# WILDERNESS AREAS

In accordance with the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, and as specifically designated by Public Law 94-557, October 19, 1976, the U. S. Geological Survey and the U. S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are now being studied. The act provides that areas under consideration for wilderness designation be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. This bulletin reports the results of a mineral survey of certain national forest lands in the Snow Mountain Study Area, California, that is being considered for wilderness designation. The area studied is in the Mendocino National Forest in Colusa, Glenn, and Lake Counties.

# CONTENTS



# ILLUSTRATIONS

## TABLES



## CONVERSION FACTORS

*Length*

| | |
|---|---|
| 1 centimeter (cm) | = 0.3937 inches (in.) |
| 1 meter (m) | = 3.281 feet (ft) |
| 1 kilometer (km) | = 0.6214 mile (mi) |

*Mass*

| | |
|---|---|
| 1 gram (g) | = 0.03527 ounce avoirdupois (oz) |
| 1 metric ton (t) | = 1.102 ton, short |

*Temperature*

| | |
|---|---|
| degrees Celsius (°C) | = (degrees Fahrenheit (°F) −32)/1.8 |

# MINERAL RESOURCES OF THE SNOW MOUNTAIN WILDERNESS STUDY AREA, CALIFORNIA

By ROBERT D. BROWN, JR., DAVID J. GRIMES, and
REINHARD LEINZ, U.S. GEOLOGICAL SURVEY, and
FRANCIS E. FEDERSPIEL and ANDREW M. LESZCYKOWSKY
U.S. Bureau of Mines

## SUMMARY

The Snow Mountain Wilderness Study Area covers about 147 km². About 190 km north of San Francisco and on the divide between the Sacramento and Eel Rivers, it contains some of the highest terrain in the Coast Ranges. Snow Mountain and St. John Mountain, the most prominent landmarks in the study area, stand more than 2,000 m above sea level; the total relief is about 1,600 m m. Roads lead to the area from Willows and Maxwell in the Sacramento Valley and from Upper Lake near Clear Lake.

To evaluate the mineral resource potential, both existing and new data are collected and interpreted in this report. New work includes geologic field studies in the west half of the area; the interpretation of data from an earlier aeromagnetic survey; geochemical interpretation based on the analysis of samples of stream sediment, rock, and springs; and the examination and sampling of prospects. The results of these investigations indicate that the mineral resource potential is low.

The outline of the study area, its elevation, and many of its landforms are closely related to its geology. Bordered by steep slopes and dissected by deep narrow canyons, the area's rugged surface and elevation have kept it remote and roadless in comparison with other parts of the Coast Ranges. The proposed boundary of the wilderness area follows a major low-angle thrust fault. Flat or gently dipping for much of its extent, this fault, which branches from the Stony Creek fault zone to the east, separates volcanic rock from the underlying weakly metamorphosed sedimentary rock. The slab of volcanic rock above the fault stands high because it resists erosion more effectively than do other rock types in the vicinity.

The volcanic rocks are of Late Jurassic age and consist chiefly of finely crystalline flows of pillow basalt, most of which is now altered to spilite. The pillow lava contains beds of sandstone, mudstone, and radiolarian chert and a few thin sills of diabase. Most of these rocks accumulated in deep water during an episode of submarine volcanism.

These rocks are faulted over cataclastic (physically deformed) sedimentary rocks that underlie much of the northern Coast Ranges and that are commonly assigned to the Franciscan Formation. Originally mudstone, siltstone, and sandstone, these sedimentary rocks now are deformed to phyllonite and semischists. They contain a few thin flows of intensely altered pillow lava, evidence that they accumulated in a marine environment, probably during Late Jurassic and Cretaceous time.

A belt of sheared and crushed rock as much as 250 m thick separates the volcanic rock above the thrust fault from the cataclastic sedimentary rock below. The sheared and crushed debris is chiefly cataclastic sedimentary rock, but it contains some resistant masses derived from the volcanic slab and a few exotic rock types such as glaucophane schist. Most of the prospects and claims in the study area are in this belt of rocks or another that is similar but structurally lower.

Serpentinite, in tabular masses and in lenses, occurs both along thrust faults and along high-angle faults. The most extensive serpentinite body follows a northwest-trending fault along the Middle Fork of Stony Creek

Unconsolidated deposits cover a small portion of the study area. They include glacial and glaciofluvial deposits, landslide debris, terrace deposits, and alluvium.

The geology, as well as records of past mineral exploration and production, gives clues to the mineral resource potential. Chromium, copper, manganese, and mercury have been mined from similar rocks in other parts of the Coast Ranges. At The Geysers, a steam field in the northern Coast Ranges, geothermal power is produced in a somewhat similar geologic setting. The potential for these and other resources can be evaluated by analyzing and interpreting the geologic, geochemical, and aeromagnetic data. The results, summarized in this report, disclose no important resource potential within the study area. Variations in geochemical properties and anomalies in the aeromagnetic data can be explained by normal chemical and physical properties of the rock units within the area; nowhere do the geochemical or magnetic data indicate unusual concentrations of mineral commodities.

These findings are consistent with the history of exploratory activity; the little previous prospecting done in the Snow Mountain Wilderness Study Area has not revealed commercial mineral deposits. According to courthouse records, only 19 lode claims have been located in, or adjacent to, the study area. Most of the claims were for manganese. Samples from manganese-bearing chert beds east of the area have the highest manganese contents, as much as 33.6 percent. These deposits have been mined, mainly during World Wars I and II. Chert with manganese oxide coatings on bedding and fracture surfaces occurs in the study area, but the size and grade of these deposits are not sufficient for them to be considered a resource. Serpentinized peridotite crops out on some claims in the area, but analyzed samples contained no more than 0.47 percent $Cr_2O_3$ and 0.26 percent nickel. In the east part of the study area, one claim has been located for onyx and another for nephrite jade. No semiprecious gemstones were found during this investigation.

Mineral springs formerly exploited at a spa near Fouts Springs no longer appear to have much resource value. Volcanic rocks and diabase suitable for crushing and for use in construction cover much of the study area; they have not been commercially exploited.

## INTRODUCTION

The Snow Mountain Wilderness Study Area is about 15 km long and 12 km wide and covers 147 km$^2$. It is located in the eastern part of the California Coast Ranges on the divide between coastal and Sacramento Valley drainage systems, about 190 km north of San Francisco (fig. 1). To evaluate the mineral resources of this area, scientists from the U. S. Geological Survey and the U. S. Bureau of Mines conducted field investigations of the study area and its surroundings during the summer of 1977. The results, described in this report, are consistent with previous interpretations of the geology and disclose no evidence of important mineral resources.

The study area is encircled by roads of the U. S. Forest Service in the Mendocino National Forest and is accessible by several alternate

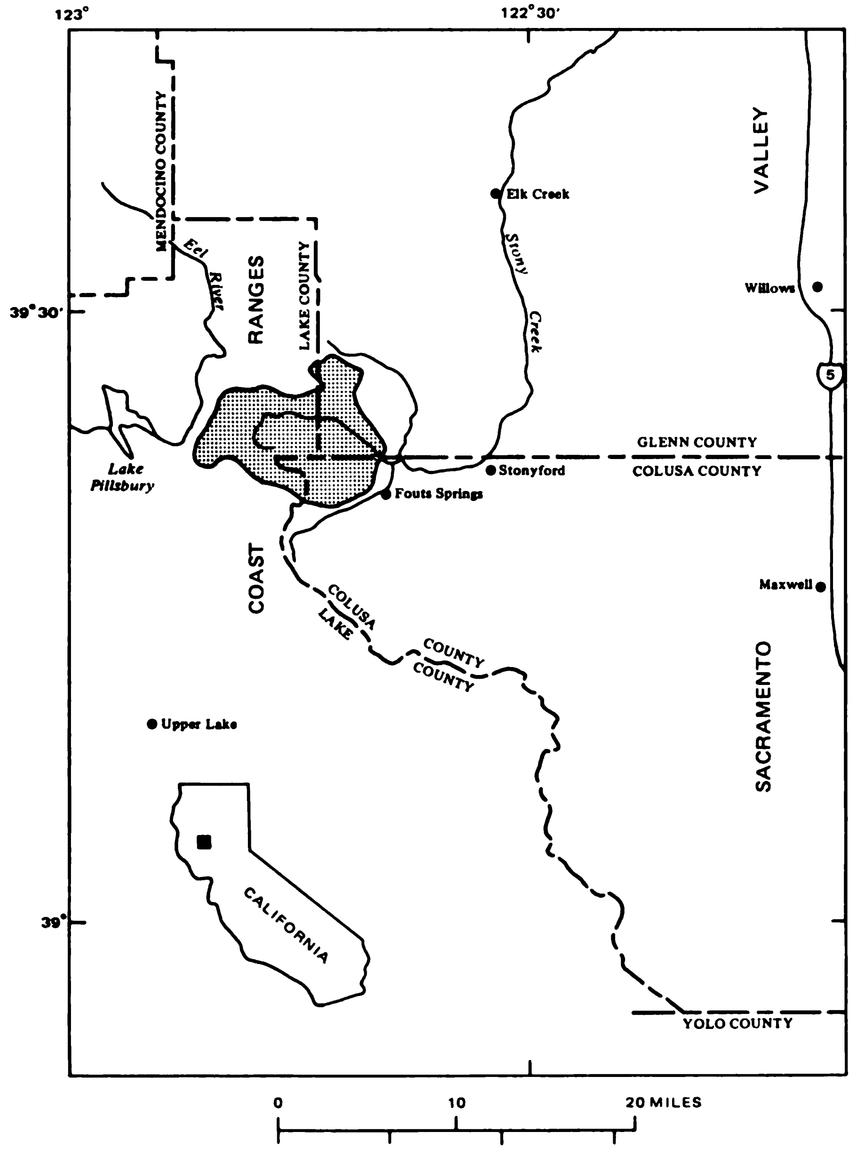



FIGURE 1.- Location of Snow Mountain Wilderness Study Area (shaded).

routes. From Maxwell on U. S. Interstate Highway 5, a paved road goes to Stonyford and from there to Fouts Springs on the east side of the area, a total distance of about 60 km. From Willows, also on Interstate Highway 5, State Route 251 (Willows to Elk Creek) and Forest Service roads 20No1 and 24No2 lead to the north side of the study area at Low Gap, a distance of about 60 km. From Upper Lake on State Route 20, the west side of the area is accessible via about 25 km of Forest Service roads. These roads link with roads that roughly follow the periphery of the study area. Some of the roads are improved but many are not, and at times access is difficult because of snow, washouts, or landslides. Advice on current road conditions is available at the Mendocino National Forest headquarters in Willows and at District Ranger Stations in Upper Lake and Stonyford.

Well-maintained trails penetrate the interior of the study area, with trail heads at, or near: West Crockett Camp, Upper Nye Camp, the switchback on the road near map elevation 3,760 feet (1,146 m) (3.2 km southeast of the summit of St. John Mountain, St. John Mountain 7½-minute quadrangle), Bonnie View, Moon Glade near Fouts Springs, Deafy Glade, and Summit Spring. A designated vehicular access trail, suitable for four-wheel drive vehicles and trail bikes, follows the ridge west of the Middle Fork of Stony Creek for several kilometers; it joins Forest Service roads 18No4 and 24No2 about 0.5 km north of West Crockett Camp.

Much of the terrain is steep and rugged; the total relief is about 1,600 m. The highest points, Snow Mountain East, 2,151 m above sea level, and St. John Mountain, 2,056 m, are separated by the canyon of the Middle Fork of Stony Creek. Their lower slopes, both along the Middle fork and around the margin of the study area, are steep and in some places precipitous. Most of the land surface is deeply dissected by V-shaped canyons with steep stream gradients. An area of several square kilometers around Snow Mountain exhibits relatively low relief with many flat or gently sloping surfaces and broad accordant ridge crests. Stream gradients in this area are lower, and several streams that drain north and east from Snow Mountain occupy U-shaped hanging valleys above the 1,800-m level.

Except for the summit area around Snow Mountain and a few precipitous canyon walls, the terrain is covered with brush, timber, and grass. The density and kind of vegetation vary with elevation. Above 2,000 m the surface around Snow Mountain is barren or is dotted with a few stunted trees and shrubs. Below the summit and above about 1,350 m, virgin forest of pine, fir, and cedar cover most of the ridges and slopes. Below 1,350 m, dense chaparral with conifer thickets covers almost all of the surface, concealing rock exposures and making foot travel difficult. The chaparral cover is interrupted by a few of the larger streams and, on the south side of Snow Mountain, by grassy meadows or glades on the inclined, poorly drained surface of landslide deposits.

## PREVIOUS INVESTIGATIONS

The earliest published geologic report on the area around Snow Mountain is that of Holway (1911), who cited evidence of Pleistocene glaciation on the north and east sides of the mountain and noted that the bedrock was deeply weathered and diabasic. Irwin (1960) described regional geologic relations in the northern Coast Ranges and Klamath Mountains, and on a small-scale (1:500,000) map he showed the Snow Mountain area as undifferentiated rocks of the Franciscan Formation. The Ukiah sheet (1:250,000) of the Geologic Map of California (Jennings and Strand, 1960), however, shows much the same area as greenstone of the Franciscan Formation. Irwin (1960, figs. 6-16) also documented known mineral commodities in the Coast Ranges and Klamath Mountains and assembled commodity data from a number of sources. None of the mineral deposits shown on his maps is within the Snow Mountain Wilderness Study Area.

Brown (1964a, b) mapped the geology of the wilderness study area east of long 122°45' W. as part of a broader geologic study. He interpreted the volcanic rocks on Snow Mountain and St. John Mountain as the basal part of the Great Valley sequence and the lower contact of the volcanic rocks as a low-angle thrust fault. These geologic field investigations were supplemented in 1962 by an aeromagnetic survey that was bounded by long 121°52½' and 123° W. and lat 39°15' and 39°30' N. (U. S. Geol. Survey, unpub. data, 1962). Parts of this survey that are germane to this report are discussed in the section "Interpretation of Aeromagnetic Data."

Regional gravity data by Chapman and others (1974) define a positive 20-milligal Bouguer anomaly that coincides approximately with the body of volcanic rock on Snow Mountain and St. John Mountain.

The sequence of volcanic rocks surrounding Snow Mountain and described in this report are now (1977) being studied by G. J. McPherson) and are considered by him him to represent an ancient seamount (McPherson, 1977).

Several published reports summarize data on mineral commodities in the northern Coast Ranges of California. No commodities are listed for the study area, but some are found nearby and others are reported from rock types or geologic settings that are similar to those in the study area. Manganese is associated with chert outcrops at several mines and prospects near Stonyford, a few kilometers east of the study area. Only a few hundred tons of ore have been produced, chiefly during World War I (Trask and others, 1943; Trask, 1950). Chromite deposits in dunite associated with serpentinite and other ultramafic rock have been mined in other parts of the Coast Ranges, and several chromite prospects in serpentinite are reported near Stonyford (Bradley and others, 1918; Dow and Thayer, 1946). No production from the Stonyford prospects is reported, but the Gray Eagle mine, 40 km north, produced more than 31,000 metric tons of milled chromite concentrates in 1942, 1943, and 1944 (Dow and Thayer, 1946, p. 9) and much smaller amounts in the 1950's (J. P. Albers, written commun., 1978). A few abandoned copper prospects, evidently with little or no production, are located in rocks along or near the Stony Creek fault zone south of Stonyford (Aubury, 1908; Eric, 1948). Mercury, associated with altered serpentinite or with sedimentary rocks of the Franciscan Formation, has been mined at many localities in the California Coast Ranges (Davis, 1957, p. 342). All of these localities are south of Snow Mountain, and no nearby mercury deposits are known.

Thermal springs, common in other parts of the Coast Ranges, are of interest in the search for geothermal energy. Waring (1965) included Fouts or Redeye Spring in his list of thermal springs and measured its temperature range as 16° to 24°C; Berkstresser (1968) found it slightly warmer, 25.5°C.

## PRESENT INVESTIGATION

The geologic data and interpretations given here are partly from earlier field studies by R. D. Brown and partly from work by Brown and John Thompson during the summer of 1977. The geology east of long 122°45' W., which passes near the summit of Snow Mountain, is from unpublished field notes, annotated aerial photographs, and maps that were made during the period 1960-63. These field data are recompiled on 7½-minute (1:24,000) base maps of St. John Mountain and Fouts Springs quadrangles, both published in 1968. The geology west of long 122°45' W. is based partly on fieldwork done during June and July 1977 and partly on earlier geologic reconnaissance by Brown in 1962.

Geochemical samples of stream sediments and spring water were collected and analyzed by David Grimes and Reinhard Leinz during June and July 1977. They also analyzed many of the rock samples collected during the geologic fieldwork.

Francis Federspiel and Andrew Leszcykowsky examined and sampled claims and prospects and provided analytical data for these sampled localities. The geologic and geochemical field investigations were expedited by helicopter support obtained under a cooperative agreement with the U. S. Forest Service. Helicopters were employed chiefly to improve access to remote areas.

ACKNOWLEDGMENTS

The authors of this report appreciate the cooperation of property owners and local residents. Officials of the Mendocino National Forest, especially John Brooks, Resources Geologist, were particularly helpful.

## GEOLOGY

The wilderness character of the Snow Mountain area - its relief, remoteness, and indirectly even its biota - is controlled by its geology. This is well shown by the boundary of the study area, roughly defined by roads. Though made by man, these peripheral roads follow a natural break in slope along a belt of easily eroded rock; these surface features delineate a major thrust fault that encircles and passes beneath the study area. The thrust fault is thus a natural and fundamental boundary that has guided and limited access routes around the margin of the wilderness.

The rugged interior of the study area is carved almost entirely from a single large rock mass, a klippe, or fault slab, of volcanic rocks that is in fault contact with sedimentary rocks beneath it. Made up of countless flows of dense, finely crystalline pillow lava, this klippe resists erosion more effectively than do the sedimentary rocks. Like a carapace, it protects this area from the rapid downcutting and mass wasting that have reduced surrounding parts of the Coast Ranges to much lower elevations. The elevation and areal extent of this volcanic upland are unique in the northern Coast Ranges, and the upland itself constitutes an environmental island, different from nearby areas in landforms, geology, and potential resources.

The geologic history is complex and not fully known, but major events can be sketched from the geologic data. The oldest rocks, pillow lava of Late Jurassic age, record an episode of submarine volcanic activity, probably in a deep-water marine environment and near the axis of a deepening trench. Toward the end of the Jurassic, volcanic activity diminished and was succeeded by an influx of marine sediment - chiefly mud, silt, and sand. Farther east, in the area now occupied by the Great Valley, clastic marine sediment continued to accumulate throughout the Cretaceous, and it may have persisted here as well.

After burial and lithification, the Jurassic and Cretaceous rocks were folded along north-trending axes, later displaced along low-angle thrust faults, and then cut by high-angle faults with northeast and northwest trends. Although the most intense folding preceded faulting, some of it persisted until much later. The emplacement of serpentinite, or ultramafic rocks, accompanied thrusting and continued during and after later high-angle faulting. Crustal deformation of this part of the Coast Ranges may not yet have ceased, for many geologic features and landforms are difficult to reconcile with long-term crustal stability.

The final chapter of geologic history is recorded in the present landscape. Alpine glaciers sculpted the highest peaks in late Pleistocene time. Postglacial stream erosion, which continues to the present time, deepened canyons and valleys and oversteepened some slopes so much that they became unstable and moved downhill as landslides.

## VOLCANIC ROCKS OF LATE JURASSIC AGE

Snow Mountain, St. John Mountain, and Crockett Peak occupy an elliptical upland area of about 120 $km^2$ that stands more than a thousand meters above the surrounding terrain. The rocks in the upland are a distinctive assemblage of volcanic flows with interbeds of sedimentary rock rich in volcanic material and a few sills of diabase.

The basal contact of the volcanic rocks is a major low-angle thrust fault that truncates bedding and structures in the volcanic rocks, separating these rocks from deformed and weakly metamorphosed sedimentary rock that crops out at lower elevations. The basal contact is warped along a north-trending axis and is about 1,000 m lower east and west of Snow Mountain than it is to the north and south. The dissected and eroded slab of volcanic rocks above the contact is locally at least 900 m thick and may be even thicker. The total stratigraphic thickness of the volcanic rocks is at least 1,000 m and may be as much as 1,500 m because rocks within the slab are tilted and folded.

Although the slab of volcanic rocks is a klippe and structurally isolated by the fault surface at its base, its relation to other geologic units can be deduced from mapped geologic relations with rocks on the east. Similarities in both lithology and structural setting are cited in an earlier work (Brown, 1964a) as evidence that the volcanic rocks on Snow Mountain and those that crop out above a similar basal thrust fault a few kilometers to the east, near Stonyford, are part of the same volcanic unit. The outcrop area near Stonyford, about 25 $km^2$, is separated from that on Snow Mountain by the deeply eroded canyons of the North and South Forks of Stony Creek. Both of these streams cut below the level of the basal thrust fault, but the gap between the two bodies of volcanic rocks in most places is less than 3 km. Mapped field relations in the upper part of the volcanic rocks near Stonyford provide evidence that these rocks underlie and locally may interfinger with dark-gray tuffaceous siltstone and sandstone near the base of the Great Valley sequence. This 13,000-m-thick sequence of bedded siltstone, sandstone, and conglomerate underlies the Sacramento Valley of California and crops out in an east-dipping homocline in the range of low hills east of Stonyford. It includes rocks of Late Jurassic and Cretaceous age, but because rocks that immediately overlie the volcanic rocks at Stonyford are Late Jurassic, the volcanic rocks also have been considered to be of Late Jurassic age (Brown, 1964b).

The interpretation that the volcanic rocks in the slab above the thrust fault are a lower part of the Great Valley sequence (Brown, 1964a) is followed in this report. Older published geologic maps (examples are Irwin, 1960; Bailey and others, 1964; Jennings and Strand, 1960) include these volcanic rocks in the Franciscan Formation, the deformed and weakly metamorphosed rock that underlies much of the California Coast Ranges.

Pillow lava is the most abundant rock type in the volcanic sequence. It consists of finely crystalline volcanic rocks in pillow-shaped masses a meter or two in diameter that accumulated as piles or flows while the lava within individual pillows was still hot and plastic. The pillows exhibit draping and conformity of the base of younger pillows to the upper surface of those beneath. Discrete flows are difficult to distinguish, but most are probably a few tens of meters thick; thinner flows, 2 or 3 m thick, are associated with breccias or sedimentary rocks in a few places.

The pillow lava is dense, finely crystalline, and dark colored; individual pillows have thin devitrified or glassy rinds and contain a few small (1 to 2 mm) vesicles near the outer pillow surfaces. Freshly broken surfaces are dark greenish gray (5G4/1) (Goddard and others, 1963) or medium dark gray (N4), depending on the degree of weathering and alteration and the abundance of altered feldspar phenocrysts in the rock. Hand specimens from most flows are dense and megascopically nearly featureless; with a 10-power lens, laths and needles of feldspar, a few augite laths, and characteristic volcanic rock textures are visible. Most crystals of augite and feldspar are less than a millimeter long and are enclosed in a glassy or finely crystalline matrix. In some specimens, veins and masses of pyrite and vesicle fillings of calcite and chlorite are visible with a lens.

Porphyritic pillow lava, less common than the dense finely crystalline variety, crops out in a belt extending west from Signal Peak and at scattered localities west, north, and east of Snow Mountain. These rocks and similar massive porphyritic rocks without pillow structure contain large (5 to 10mm) phenocrysts of altered pale-green feldspar, which constitutes as much as 40 percent of the rock. The color (greenish gray, 5G6/1) and the abundance and size of the feldspar phenocrysts are distinctive in outcrop and hand specimens. The belt west of Signal Peak is differentiated on the geologic map (pl. 1).

Massive amygdaloidal flows without pillow structure crop out in a few places. These flows are medium dark gray (N4) on fresh surfaces but weather to grayish red (5R4/2). Although dense and finely crystalline, they are somewhat coarser textured than typical pillow lava and contain more and larger amygdules.

In thin section, volcanic rock samples exhibit chiefly variolitic and intersertal textures in which plagioclase and augite are enclosed in a devitrified groundmass. Plagioclase laths in the groundmass and plagioclase phenocrysts as much as 10 mm in diameter are clouded with alteration products; chlorite and calcite are the most abundant. Where the composition of the feldspar can be determined optically, it is albite, or, in a few rocks, sodic andesine. In many sections, the intensity of alteration precludes accurate determination of plagioclase. Neutral or pale-brown augite, much less abundant than either plagioclase or groundmass, forms granules and subophitic intergrowths. The groundmass in most sections is finely crystalline and consists of microcrystalline feldspar, chlorite, uralite, and rarely quartz or epidote; in a few sections it is opaque brown or black glass with an index of refraction greater than 1.540. Chlorite and calcite are the chief amygdule minerals, and in some rocks they are accompanied by quartz. Quartz, chlorite, and calcite fill veins and fractures.

The abundance of albite, the intensity of alteration, and the textures of these rocks are characteristic of spilite, a rock that is high in soda and low in silica and potassium but that otherwise resembles normal basalt. Similar spilitic pillow lava on the Olympic Peninsula in Washington State contains numerous small deposits of mangnese as well as one larger deposit at the Crescent mine, once the leading producer of manganese in the United States.

Chemical analyses of seven samples of pillow lava and diabase from the volcanic outcrop area near Stonyford (Bailey and Blake, 1974; table 1, this report) show many characteristics of spilite, but thin sections of some samples of Stonyford rocks contain labradorite rather than albite and therein more closely resemble normal basalt. The spilitic albitized rock appears to be more abundant to the west, on Snow Mountain, than eastward toward St. John Mountain and Stonyford. Geologic structure in the volcanic rock (pl. 1) can be interpreted as evidence that progressively younger rock is exposed to the east; if this is so, the intensity of albitization may be a function of stratigraphic position or depth of burial, or possibly both.

TABLE 1. - *Chemical analyses of basalt, diabase, and spilite from volcanic rocks near Stonyford*
[From Bailey and Blake, 1974]

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 46.2 | 46.5 | 47.5 | 48.2 | 49.0 | 49.2 | 49.5 |
| $Al_2O_3$ | 16.6 | 14.6 | 13.5 | 13.2 | 14.8 | 13.0 | 13.0 |
| $Fe_2O_3$ | 6.3 | 5.0 | 3.3 | 3.4 | 3.4 | 4.6 | 4.7 |
| FeO | 4.2 | 6.4 | 7.3 | 8.4 | 6.1 | 8.1 | 8.6 |
| MgO | 5.2 | 6.8 | 4.0 | 5.5 | 7.2 | 5.2 | 5.7 |
| CaO | 8.5 | 7.9 | 11.0 | 9.7 | 7.9 | 9.3 | 8.3 |
| $Na_2O$ | 4.2 | 2.2 | 3.3 | 3.4 | 4.2 | 2.8 | 4.3 |
| $K_2O$ | .82 | 2.3 | .54 | .32 | .78 | .24 | .53 |
| $H_2O+$ | ... | 4.2 | 2.3 | ... | ... | 2.0 | ... |
| $H_2O-$ | 4.8 | ... | .67 | 3.9 | 4.1 | .73 | 2.40 |
| $TiO_2$ | 2.3 | 2.5 | 2.5 | 2.3 | 1.9 | 3.0 | 2.3 |
| $P_2O_5$ | .44 | .34 | .31 | .26 | .32 | .11 | .27 |
| MnO | .20 | .38 | .25 | .18 | .19 | .22 | .27 |
| $CO_2$ | .34 | .70 | 3.8 | .15 | .27 | .25 | .14 |
| Sum | 100.1 | 99.8 | 100.3 | 98.9 | 100.2 | 98.7 | 100.0 |
| Density | 2.73 | 2.76 | 3.00 | 2.84 | 2.86 | 3.00 | 2.94 |

1. Spilite (BSO-108), Dry Creek, Glenn County, Calif. Analysis by I. Barlow, S. Botts, G. Chloe, and P. Elmore.
2. Diabase (BSO-91), Stony Creek, Colusa County, Calif. Analysis by I. Barlow, S. Botts, G. Chloe, and P. Elmore.
3. Basalt (SF-70-1), Stony Creek, Colusa County, Calif. Analysis by S. Botts.
4. Basalt (BSO-107), Stony Creek, Colusa County, Calif. Analysis by I. Barlow, S. Botts, G. Chloe, and P. Elmore.
5. Spilite (BSO-94), Stony Creek, Colusa County, Calif. Analysis by I. Barlow, S. Botts, G. Chloe, and P. Elmore.
6. Diabase (SF-70-2), Stony Creek, Colusa County, Calif. Analysis by S. Botts
7. Spilite (BSO-90), Stony Creek, Colusa County, Calif. Analysis by I. Barlow, S. Botts, G. Chloe, and P. Elmore.

Keratophyre, a light-colored silica-rich volcanic rock that often is associated with spilite and is reported from other localities in the California Coast Ranges (Bailey and Blake, 1974), is evidently uncommon here. One keratophyric rock unit containing microcrystalline albite and quartz crops out on Snow Mountain West; similar rocks were not found elsewhere in the study area.

Volcanic breccia and tuff are locally interbedded with pillow lava and massive volcanic rocks. Lenses and beds of breccia and tuff are especially abundant on ridges extending north and northeast from Snow Mountain East and on the north side of St. John Mountain. Breccia clasts resemble the rock in volcanic flows, and most clasts are angular and a few centimeters in diameter. A few beds of breccia and lapilli tuff grade laterally or vertically into marine sedimentary rocks, and some breccia units appear to interfinger with flows of pillow lava.

Beds of marine sedimentary rocks occur throughout the volcanic pile but are thickest and most extensive near the northern and eastern boundaries of the thrust slab, where some mapped sedimentary units are more than 100 m thick. The thickest sedimentary units were derived from mudstone or siltstone containing thin (1-5 cm) sandstone beds; they are now weakly metamorphosed to argillite and weather to pencil-shaped fragments bounded by cleavage surfaces. Most of the argillite is medium dark gray (N4) or medium gray (N5); tuffaceous beds are grayish red (5R4/2 to 10R4/2) or brownish gray

(5YR4/1 to 4YR6/1), but in outcrop, distinctively red or purple. Bedded chert as thick as 50 m immediately underlies or overlies many argillite sequences, and, in a few places, bedded chert also separates individual volcanic flows. Most chert units are red; some are green or white and a few are pale blue; many of the thicker units are contorted and folded with fold amplitudes of a few meters. Almost all of the chert is regularly bedded; beds are one to a few centimeters thick. A few beds are dotted with the tests of radiolarians, others coated with or veined by manganese oxides.

Although several manganese prospects are located on chert outcrops near Stonyford, no large or extensive deposits of manganese were found in the study area.

Sills of diabase are interlayered with the volcanic rocks. Only a few of the thicker (15-35 m) sills are shown on the geologic map (pl. 1), because thinner ones are difficult to trace. The mapped sills dip gently (30° or less), resist erosion well, and form broad smooth upland surfaces. Most of the sills, however, are only a few meters thick and are more subtly expressed in the topography. One sill about 8 m thick that overlies less resistant pillow lava forms the lip of a 15-m waterfall in the Middle Fork of Stony Creek about 750 m upstream from the pack trail crossing south of West Crockett Camp. Like most sills, it is emplaced along the bedding and follows a thin unit of sedimentary rocks and chert between much thicker flows of pillow lava.

Thin sections of diabase exhibit diabasic to intersertal textures with interstitial chlorite between plagioclase and augite. Both primary minerals and alteration products are similar to those described in pillow lava. Crystallization is more complete in the diabase, and large crystals of albite and augite are much more abundant than groundmass. The kinship of the diabase with the pillow lava is evident from chemical analyses of rocks from the Stonyford area (Bailey and Blake, 1974; table 1, this report). The similarity in mineralogy and chemical composition, the absence of contact metamorphism, and the general concordance of the sills with layering in the volcanic rocks support the view that the diabase is part of the same volcanic episode that produced the flows of pillow lava.

The thick piles of pillow lava, the interbeds of tuffaceous mudstone and siltstone, and the beds of radiolarian chert are evidence of volcanism on the sea floor in deep water. Similar rocks typically are found in subsiding marine depositional basins throughout the world (Turner and Verhoogen, 1960, p. 257-272). Some of the rock masses described here, especially the massive amygdaloidal flows, may have accumulated on volcanic islands or on land above sea level; they constitute a relatively small part of the volcanic rock sequence.

Indirect stratigraphic evidence that the volcanic rocks are of Late Jurassic age (Brown, 1964a) has been described earlier in this report. This age is confirmed by radiolarian fossils from two areas. Pessagno (1977, p. 63-66, 104) described radiolarians from a chert bed in volcanic rocks on Stony creek near Stonyford and assigned them to his radiolarian zone 2B, which is indicative of the early Tithonian (Upper Jurassic). Pessagno's locality (0.6 km downstream from the diversion dam on Stony Creek) is east of the study area in similar and presumably correlative rocks.

Another radiolarian chert locality near Bear Wallow Creek is within the area. Radiolarians from this locality, at map elevation 4,000 feet (1,219 m), on a ridge crest 450 m northeast of the confluence of Bear Wallow Creek and the Middle Fork of Stony Creek, were examined by D. L. Jones (oral commun., 1977) and are considered by him to indicate about the same stratigraphic level as those identified by Pessagno.

Although the volcanic rocks are considered to be of Late Jurassic age, some of them that are stratigraphically lower than the two chert localities may be older.

### CATACLASTIC SEDIMENTARY (FRANCISCAN) ROCKS OF LATE JURASSIC AND CRETACEOUS AGE

The slopes bordering the study area rise steeply from incised streams: the Eel River on the west, the South Fork of Stony Creek on the southeast and east, and the North Fork of Stony Creek on the northeast. Above these streams and below intensely sheared rocks along the thrust fault at the base of the volcanic slab, the slopes are underlain by deformed and weakly metamorphosed sedimentary rocks that contain a few thin flows of pillow lava. The upper contact of the sedimentary rocks with the sheared and crushed rocks along the fault zone, or with volcanic rocks in the upper plate of the thrust, is flat or gently dipping. These contact relations, shown on the geologic map (pl. 1), are part of the evidence that the volcanic upland is a klippe and that the sedimentary rocks are continuous at shallow depth beneath it (cross sections, pl. 1).

Similar cataclastic rocks are well exposed for many kilometers south and east of the volcanic upland. North and west, the continuity of these rocks is partly obscured by younger rock units and landslide deposits, but here too they are probably continuous at shallow depth. These and similar cataclastic sedimentary rocks elsewhere in the California Coast Ranges formerly were considered a part of the Franciscan Formation by most geologists (Bailey and others, 1964; Jennings and Strand, 1960). Despite lithologic similarities, most of the evidence now available suggests that the Franciscan is not a fundamental lithologically homogeneous unit but a complex of tectonic slices of varied lithology derived from several sources. In this report, the term Franciscan Formation is not employed, although the affinity of the cataclastic sedimentary rocks with other Franciscan rock types is recognized. The largest area of outcrop of these rocks is on the southeast side of Snow Mountain between Fouts Camp and the South Fork of Stony Creek. There they are probably more than 800 m thick, but the absence of marker beds and small-scale folding and faulting make thickness estimates uncertain.

The sedimentary rocks are distinctively crushed and sheared and exhibit a cataclastic texture that is easily seen with a lens. Most of these rocks are fine grained and were probably derived from mudstone or siltstone. The fine-grained rocks are now weakly metamorphosed to phyllonite in which pervasive, closely spaced shear surfaces parallel or nearly parallel the bedding. Where metamorphism is most intense, the surfaces of schistosity exhibit a sheen that is probably a product of recrystallization. Exposed rocks are medium dark gray where fresh; most are weathered to light olive gray.

Semischist, derived from fine- to medium-grained arkosic wacke and sandstone, is interbedded with the phyllonite, and in some places predominates over the finer grained rocks. Beds of semischist are a few millimeters to several centimeters thick, are well bedded, and may or may not be graded. Some beds exhibit sole marks, slump folds, and load casts; these and other bedding features are difficult to distinguish where the degree of cataclastic deformation is high, as it is in much of the area described here. Individual grains in the semischist are flattened and sheared and are separated by streaks of sheared dark matrix so that the original grain outline and sedimentary texture is obscured in many rocks.

Pillow lava in flows no thicker than 100 m is interbedded with the cataclastic sedimentary rocks on Skeleton Creek both east and west of the road crossing and on the south Fork of Stony Creek below Deafy Glade. Pillow forms and other field relations resemble those in the volcanic rocks of Late Jurassic age except that the volcanic rocks interbedded with cataclastic sedimentary rocks are more broken and deformed and are more intensely altered. Although typical volcanic textures are visible with a lens, thin sections exhibit few identifiable primary minerals and are clouded with a nearly opaque mass of alteration products through which the original texture is vaguely outlined.

The marine origin of these rocks is indicated by pillow lava, by marine fossils collected from similar rocks a few kilometers southeast (Brown, 1964b), and by bedding features that reflect a deep-water environment. The cataclastic fabric is a product of deformation after deposition and lithification, and because this fabric is most intense near thrust faults, the cataclastic metamorphism probably is roughly contemporaneous with thrusting.

The Late Jurassic and Cretaceous age assigned these rocks is tentative and based on indirect evidence. Similar but somewhat less deformed sedimentary rocks with thin (100-m) flows of pillow lava, 8.5 km southeast of Fouts Springs, contain fossils that were identified by D. L. Jones (oral commun., 1961) as *Buchia piochii* (Late Jurassic) and *Buchia crassicolis* (Early Cretaceous). The rocks at the fossil localities cannot be traced continuously to the study area, but because they lie along the same structural trends and are lithologically similar, they are judged to be about the same age.

### SHEARED AND CRUSHED ROCKS ALONG FAULT ZONES

Two belts of sheared and crushed rock debris were recognized and mapped. Most of the claims and prospects and many of the geochemical anomalies in the study area are within or near these two belts. The upper belt nearly circumscribes the volcanic upland about Snow Mountain and St. John Mountain, separating the volcanic rocks above it from cataclastic sedimentary rocks below. The lower belt follows the South Fork of Stony Creek from Fouts Springs to Deafy Glade. The rocks above and below the lower belt are chiefly cataclastic phyllonite and semischist. Near Deafy Glade, this belt appears to climb toward the west and may merge with the upper one beneath landslide deposits west of Summit Spring. Both belts follow major faults and are similar in field relations and lithology. The upper belt, better exposed and thicker, is described below.

The contact between the upper belt and the overlying volcanic rocks is abrupt and well defined in most places. The contact between the upper belt and the underlying cataclastic sedimentary rocks is less distinct. The upper belt is about 250 m thick where best exposed on the south and west flanks of Snow Mountain. It is thicker north and northwest of St. John Mountain and much thinner around the periphery of the volcanic slab between Crockett Peak and Copper Butte Creek. Along the southeastern and eastern margin of Snow Mountain, volcanic rocks are in fault contact with phyllonite and semischist, and no mappable belt of sheared and crushed rocks intervenes.

Most of these rocks consist of a finely divided, fragmented matrix that encloses much larger masses of resistant rocks. Angular matrix fragments are of argillite or mudstone and range in size from about a millimeter to 20 mm. Such debris is derived chiefly from the cataclastic sedimentary rocks of Late Jurassic and Early Cretaceous age or their unmetamorphosed equivalents.

Within this sheared argillaceous matrix are larger blocks of resistant rocks: graywacke, diabase, massive volcanic rocks, chert, glaucophane-bearing rocks, and glaucophane schists. These resistant masses range from about a meter to more than 100 m in diameter, the larger ones standing out like chaotic monuments above the surrounding terrain. Many are obviously recrystallized, and some show tectonically abraded and altered borders. They are most abundant near the upper contact of the sheared and crushed rocks with pillow lava, and where they are clearly in place, most of the exotic recrystallized masses, like glaucophane schist, are within a few tens of meters of the contact. Quartz veins cut both the finely divided debris and the resistant masses. Rock debris of this lithology was previously described and mapped as "friction carpet debris" (Brown, 1964a). Near St. John Mountain it is somewhat better indurated and contains more quartz veins than in the slopes above the Eel River, where it is less cemented and more easily eroded.

The lithologic character is somewhat different in the fault zone north of Summit Spring and south of Snow Mountain. Here discrete flat or north-dipping lenses of intensely sheared phyllonite and semischist 100-200 m long and 50 m thick are bounded by fault surfaces. Finely divided sheared rock is less abundant here than elsewhere, and resistant masses of glaucophane schist and other rocks mark the upper part of the belt.

Other features that help identify the belt of sheared and crushed rocks are serpentinite, large springs, and landslides. Several tabular bodies of serpentinite are mapped near the contact with the overlying volcanic rocks, and smaller wisps and irregular masses of serpentinite lie wholly within the belt of sheared and crushed rocks. Springs are abundant, especially near the upper contact, and many are surrounded by travertine aprons; only a few of the larger and most accessible springs are shown on published topographic maps. Landslides are much more numerous in these rocks than in the more resistant bedrock units above and below them. Although many of these landslides mask field relations and obscure the continuity of mapped rock units, the landslide debris is clearly derived from the belt of sheared and crushed rocks.

The sheared and crushed rocks along fault zones are a product of deformation during faulting. The age of faulting and deformation is not known but is presumed to be Tertiary for reasons discussed later in the section on "Structural Geology."

### SERPENTINITE

Serpentinite is exposed along faults and shear zones at scattered localities shown on the geologic map. Tabular masses, sheets, and lenses of serpentinite as thick as 50 m crop out in the sheared rocks just below the volcanic rocks on the head of Bear Wallow Creek, on the east side of St. John Mountain, and on the southeast and southwest sides of Snow Mountain. These serpentinite bodies parallel major lithologic contacts and nearby fault surfaces; thinner bodies on the south and west side of Snow Mountain are oriented more erratically with respect to contacts and faults. All of these bodies are in the upper belt of sheared and crushed rocks, but serpentinite also crops out in the lower belt between Summit Spring and the South Fork of Stony Creek.

Another serpentinite body, about 25-50 m thick, lies along a high-angle fault that parallels the Middle Fork of Stony Creek between Brittan Ranch and West Crockett Camp. It crops out almost continuously for about 14 km and evidently extends to substantial depth because it produces a well-defined magnetic anomaly.

Fresh unsheared serpentinite is medium dark gray (N4) or medium gray (N5) and exhibits relict textures of the parent ultramafic rock. Most serpentinite is intensely sheared and slickensided and is of paler color.

The extent to which these rocks are serpentinized makes it difficult to determine their original mineralogy and to identify the parent rock. Where original minerals can be identified, the abundance of pyroxene is considered evidence that most of the original rock was a peridotite. Dunite, a peridotite composed almost entirely of olivine, was not observed, although it or its serpentinized counterpart may be present in places. The paucity of dunite is significant because most of the known chromium deposits in the Coast Ranges and in southwestern Oregon occur in dunite.

Some of the serpentinite and other ultramafic rocks in the California Coast Ranges are believed to represent oceanic crust and to be pre-Cretaceous in age (Bailey and others, 1970; Lanphere, 1971). The age of crystallization and the history of the rocks described here is unknown. Although they may somehow be derived from ancient oceanic crust, their structural relation to other rocks shows that they were emplaced after a major episode of folding and probably during or after thrusting of the volcanic slab over cataclastic sedimentary rocks. Emplacement of the serpentinite along the Middle Fork of Stony Creek is almost surely later than thrusting, for the serpentinite follows a high-angle fault that displaces the basal thrust contact of the volcanic rocks. The age of serpentinite emplacement is therefore probably Tertiary.

## UNCONSOLIDATED DEPOSITS

Evidence of glaciation on Snow Mountain was first recognized by Holway (1911), who described a number of glacial features and deposits on the north and east sides of the mountain. Although no systematic effort was made to map glacial deposits during the field investigations on which this report is based, one deposit of presumed glacial and glaciofluvial origin has been outlined in the drainage of Dark Hollow Creek, east of Snow Mountain, where it mantles benches, ridges, and slopes as much as 120 m above the present course of the creek. It consists chiefly of angular to subangular pebbly and sandy detritus of local origin and encloses large blocks of volcanic rocks and chert. This deposit and others described by Holway are associated with cirques, hanging valleys, and other glacial features, mostly above the 1,800-m level. These glacial deposits are the most southerly glacial features known in the Coast Ranges. They are assumed to be of late Pleistocene age.

Landslide deposits of jumbled debris cover broad areas north of St. John Mountain and south of Snow Mountain between North Glade and Summit Spring. These and many smaller landslides originated in the sheared and crushed rocks along thrust faults. The deposits are easily recognized by hummocky surfaces lacking any well-established drainage network; by springs, ponds, and undrained depressions; and by steep arcuate headwalls. Landslide deposits on the south side of Snow Mountain are mottled with grassy hummocky meadows or glades, some of which (North, Mauser, Deafy, Rattlesnake, Welton) are identified on the topographic map. The landslide debris is a chaotic mixture of varied rock types. Finely divided and intensely sheared debris has enclosed and carried along resistant blocks as much as several tens of meters long and equally thick; these blocks include volcanic rocks, serpentinite, diabase, chert, and exotic rock masses from the belt of sheared and crushed rocks.

Landslide deposits also are derived from other rock units. Several large landslide deposits along the north side of the Middle Fork of Stony Creek contain both serpentinite and volcanic debris. Failure probably began in or near the belt of serpentinite. Dense vegetation and uniform lithology make landslide deposits difficult to recognize in the volcanic rocks of Late Jurassic age unless distinctive landforms such as headwalls or hummocky topography are evident or the landslide debris overrides lower rock units of different lithology. Landslide deposits in the volcanic rocks may therefore be more abundant than indicated on the geologic map.

Some landslide deposits appear to be stable and may be as old as Pleistocene, but others are still moving. The large slide area between North Glade and Summit Spring (pl. 1) and several smaller slides along the Forest Service road between Deer Creek and Copper Butte Creek are active, at least locally. At one of the smaller slides, on Hummingbird Creek, the removal of rock in a roadcut has accelerated sliding and has caused a series of steplike failures marked by open fractures and tilted and toppled trees. Other active landslides are found where stream erosion has carved steep unstable slopes in the sheared and crushed rocks beneath the volcanic slab; many of these are too small to show on the geologic map.

Terrace deposits along the North and South Forks of Stony Creek record earlier higher levels of stream deposition. Terrace remnants, a meter or two thick, are found at several levels from a few meters to tens of meters above present stream channels. The deposits are chiefly subangular to subrounded pebble and cobble gravel and consist of debris derived from upstream within the present drainage area of Stony Creek.

Alluvial deposits are thin and of local extent. Only those near Milk Ranch and near West Crockett Camp are large enough to show on the geologic map (pl. 1), but small patches of alluvium are found in relatively flat reaches of the upper course of the Middle Fork and along some of the smaller streams. On many streams, cones and fans of alluvium mark the confluence of steeper tributaries with the trunk stream. The alluvial deposits are sand and gravel, chiefly subangular to subrounded and of local origin. They are probably all of Holocene age, and some of those on the Middle Fork, upstream from Bear Wallow Creek, are so recent that vegetation on them is only poorly established.

## STRUCTURAL GEOLOGY

The structural relations shown on the geologic map and on the cross sections (pl. 1) are interpreted chiefly from the distrubution of the major lithologic units. Because of the high relief (more then 1,600 m), the geologic map provides an approximate three-dimensional model of the structure. Bedding in the sedimentary rocks and layering of pillow lava, both represented by strike and dip symbols on the geologic map, help in interpreting the structural relations. Although not all pillow flows accumulate as horizontal sheets, most flows mapped here evidently formed nearly horizontal deposits when extruded. Attitudes from several exposures of pillow lava in the same area are consistent within 5° to 10° in both strike and dip, and where pillow lava and marine sedimentary rocks are found together or in proximity, their strike and dip are similarly consistent. The contacts of younger pillows draped over older, visible at most exposures, demonstrate that nearly all of the volcanic rocks are right side up; in only a few places near faults are they overturned.

### FOLDS

Pillow flows and sedimentary beds in the volcanic rocks of Late Jurassic age are tilted, and most of them dip at angles of 60° or less. The direction of dip and the trend of bedding and layering in pillow flows vary but are generally consistent with a series of ill-defined north- to northeast-trending fold axes. The best defined fold is anticlinal, trends a little east of north, and passes through the alluvial meadows at the Milk Ranch. It plunges toward the south and appears to die out northeastward toward the Middle Fork of Stony Creek. Volcanic rocks on the limbs of the fold dip about 40°, on the average, and those on its south-plunging nose dip about 30°.

Large folds are less well defined in the intensely deformed rocks immediately beneath the thrust; at deeper structural levels to the south and southeast (Brown, 1964b), the cataclastic sedimentary rocks are folded along north-trending axes.

The north-trending folds in rocks above and below the thrust fault parallel structural trends to the east in the Great Valley and are evidently part of a major regional fold system that deformed rocks as young as Paleocene near the southwestern boundary of the study area (Berkland, 1973). The folds evidently predate thrusting, as they are truncated by gently warped and relatively undeformed thrust faults.

Small folds with other trends deform the volcanic rocks immediately above the thrust fault and the cataclastic sedimentary rocks immediately beneath it. Some of these folds, tens of meters in amplitude, are represented on the map by changes in strike and dip, by local overturning, or by plotted fold axes (pl. 1). Although they vary in trend and plunge, their character is consistent with relative northward movement of the rocks above major thrust faults.

FAULTS

Thrust faults that are nearly horizontal and steeply dipping normal faults cut the rocks shown on plate 1. The low-angle thrust fault that underlies Snow Mountain is one of several similar faults that converge eastward and merge with the Stony Creek fault zone (Brown, 1964b). At several places in this area (pl. 1) and nearby, drag folds and field relations (Brown, 1964b, and unpub. data) indicate relative northward movement of upper plate rocks. Underthrusting of lower-plate rocks toward the south is equally consistent with this evidence and is more compatible with present knowledge of the regional geology; still other directions of transport have been proposed for thrust faulting in the northern Coast Ranges (Bailey and others, 1970).

The fact that surfaces of thrusting, the belt of sheared rocks along thrust faults, and the serpentinite bodies that locally occupy shear zones are not folded like the rocks in the upper and lower plate shows that thrust faulting was later than most of the folding. Because the thrust faults are much less deformed than folded rocks of Mesozoic and early Tertiary age exposed elsewhere in northern California, they are presumed to be Eocene or younger.

Most of the steeply dipping faults trend northeastward. They exhibit no consistent sense of vertical displacement, and some of them may have slipped obliquely or along the strike of the fault. Two of these faults on St. John Mountain are down to the southeast, and the more westerly one displaces the base of the volcanic rocks by at least 130 m. Northeast-trending faults on Snow Mountain exhibit equivocal evidence for direction of displacement, but where the evidence is best, they appear to be down on the northwest.

A northwest-trending fault parallels the Middle Fork of Stony Creek and is distinguished on the geologic map by a thin belt of serpentinite. On this fault, the direction and minimum amount of relative movement, down to the south and at least 420 m, are determined by the displacement of the base of the volcanic rocks between Crockett Peak and Bear Wallow Creek. North of the fault, the base of these rocks is approximately level and about 1,560 m above sea level; south of the fault volcanic rocks crop out along the Middle Fork at an average elevation of about 1,140 m. This fault, too, may have a significant strike-slip component; in places it truncates bedded sequences hundreds of meters thick.

Both the northwest- and northeast-trending faults appear to cut the base of the volcanic rocks and to penetrate the belt of sheared and crushed rocks along the thrust fault. They are therefore at least in part younger than the thrust fault.

Except for spring deposits in the belt of sheared and crushed rocks along the thrust fault, none of the faults mapped is unusually mineralized or hydrothermally altered.

## INTERPRETATION OF AEROMAGNETIC DATA

By Andrew Griscom and Robert D. Brown, Jr.

Some rock types and some kinds of ore bodies contain magnetic minerals in quantities sufficient to affect the intensity or direction of the Earth's magnetic field. Magnetic surveys, which employ magnetometers to measure magnetic intensity, are a proven method of locating magnetic ore bodies and of evaluating the mineral resource potential of unexplored areas. Because magnetic rock can be detected through forest and soil cover, nonmagnetic rock, and water, these surveys can contribute new information even where surface geology is well known. And because magnetic effects follow simple physical laws, they enable the geophysicist to test geologic interpretations through models that reproduce observed variations in the magnetic field.

Although magnetic surveys may be made on the surface, aerial surveys are commonly employed where a large area must be examined or where ground access is difficult. In the U. S. Geological Survey's wilderness evaluation program, aeromagnetic surveys are an important part of most investigations.

In the Snow Mountain area, aeromagnetic data were already available from a survey conducted by the U. S. Geological Survey in 1962. The original data were obtained along a strip 100 km long and 26 km wide that extends east from Lake Pillsbury to about the center of the Sacramento Valley. Flight lines were oriented east-west with a 1-mile (1.6 km) spacing and were flown at an average barometric altitude of 7,000 feet (2,100 m). Magnetic intensity along the flight path was continuously recorded by an airborne magnetometer, and the data were later contoured, relative to an arbitrary datum, at intervals of 10 and 50 gammas. The western one-third of this survey, which includes the Snow Mountain Wilderness Study Area, is displayed here superimposed on a generalized map of the geology (pl. 2).

The aeromagnetic map, like most similar maps, shows two levels of information, the Earth's main field and local magnetic features. The gradient caused by the main magnetic field of the Earth increases toward the north magnetic pole, and in this part of California it increases about 6 gammas per kilometer in the approximate direction N. 17° E. (Fabiano and others, 1976; Fabiano, 1975). This regional gradient amounts to about 200 gammas across the map.

The gradient of the main field is interrupted or obscured by several magnetic anomalies that yield significant information on the magnetic properties and configuration of nearby rock masses. Most of the anomalies are positive and linear; their trends vary between north and west. The largest anomaly in the study area is about 100 gammas in amplitude, trends a little north of west, and approximately parallels the Middle Fork of Stony Creek, It merges to the southeast, outside the study area, with an even larger anomaly (labeled 2,728 gammas) that trends north-northwest. Several broader anomalies are outlined in the western and southern part of the aeromagnetic map area; two of these are near the southern boundary of the study area.

That none of these anomalies shows any systematic correlation with topography is significant. Local topographic relief here is as mch as 1,200 m, and where magnetic rocks underlie such a rugged terrain, local magnetic anomalies of this kind appear on the map. Slight irregularities in the magnetic contours over Snow Mountain may be a subtle effect of very weakly magnetic rocks, but the absence of positive anomalies over ridge crests and peaks and of negative anomalies along deeply incised canyons is evidence that the volcanic rocks and the cataclastic sedimentary rocks are at most only weakly magnetic and incapable of producing the relatively large positive anomalies mapped.

The magnetic anomalies do show a systematic relation to serpentinite bodies. Most of the well-defined anomalies correspond to surface exposures of serpentinite and follow the trend of these rocks. The largest anomalies, with one exception, are associated with thick or relatively continuous bodies of serpentinite, the smaller ones with thin or less continuous bodies. The exception is the large circular anomaly that peaks at 2,728 gammas and is about midway between Stonyford and the eastern boundary of the wilderness study area. This anomaly probably represents a large serpentinite mass at relatively shallow depth beneath a cover of volcanic rocks.

The largest magnetic anomaly within the study area follows a narrow belt of serpentinite along the Middle Fork of Stony Creek. A model study of the serpentinite belt (fig. 2) indicates that it can cause the magnetic anomaly if the belt is the expression of a dike extending below sea level in the subsurface with a dip to the north of about $70° \pm 5°$. The absence of a sharp magnetic low on the north side of the anomaly implies that the dike is not vertical (see fig. 2 for the magnetic effect of a vertical dike) and that the dike extends down to sea level at least. The calculated magnetic susceptibilities range from 0.002-0.003 emu/$cm^3$ depending on the dip of the dike, typical values for serpentinite of the northern Coast Ranges (Griscom, unpub. data, 1977). The interpretation of the magnetic data given here supports the geologic conclusion that the serpentinite dike cuts, and is younger than, the major flat-lying thrust fault.

A less regular and smaller positive anomaly trends northwesterly from Deafy Glade to the Eel River. The ridgelike eastern part of this anomaly closely follows a thin serpentinite belt along a fault zone. To the west, the geology is obscured by landslide debris in most places, but small bodies of serpentinite are alined in the landslide deposits and at a few places where bedrock is exposed. These masses, though sparse, can be interpreted as evidence of a more continuous body at depth.

A major regional feature is the magnetic gradient sloping down to the west from the north-trending ridgelike high, which peaks at 2,728 gammas on the east side of the map. This gradient as discussed by Griscom (1966) is interpreted to be caused by a deeply buried magnetic mass whose top is about 1 km below sea level at the axis of the ridgelike high and slopes down to the west, reaching a depth of 8 to 10 km about 18 km west of the axis of the high. The magnetic rocks are tentatively assumed to be serpentinite.

All of the features shown on the aeromagnetic map can be accounted for satisfactorily by the magnetic properties of recognized geologic units. There may be local or disseminated magnetic mineral deposits, but within the limits of scale and level of detail of the aeromagnetic data, no evidence of such deposits was detected.

## GEOCHEMICAL INVESTIGATIONS

The geochemical investigation in the Snow Mountain Wilderness area consists of (1) the sampling and analysis of rocks, stream sediments, pan concentrates, and spring water; (2) the plotting of geochemical maps; and (3) the interpretation of the data in relation to the geologic setting.

The rocks in the study area are similar to rocks in other parts of the California Coast Ranges that contain deposits of chromite, man-

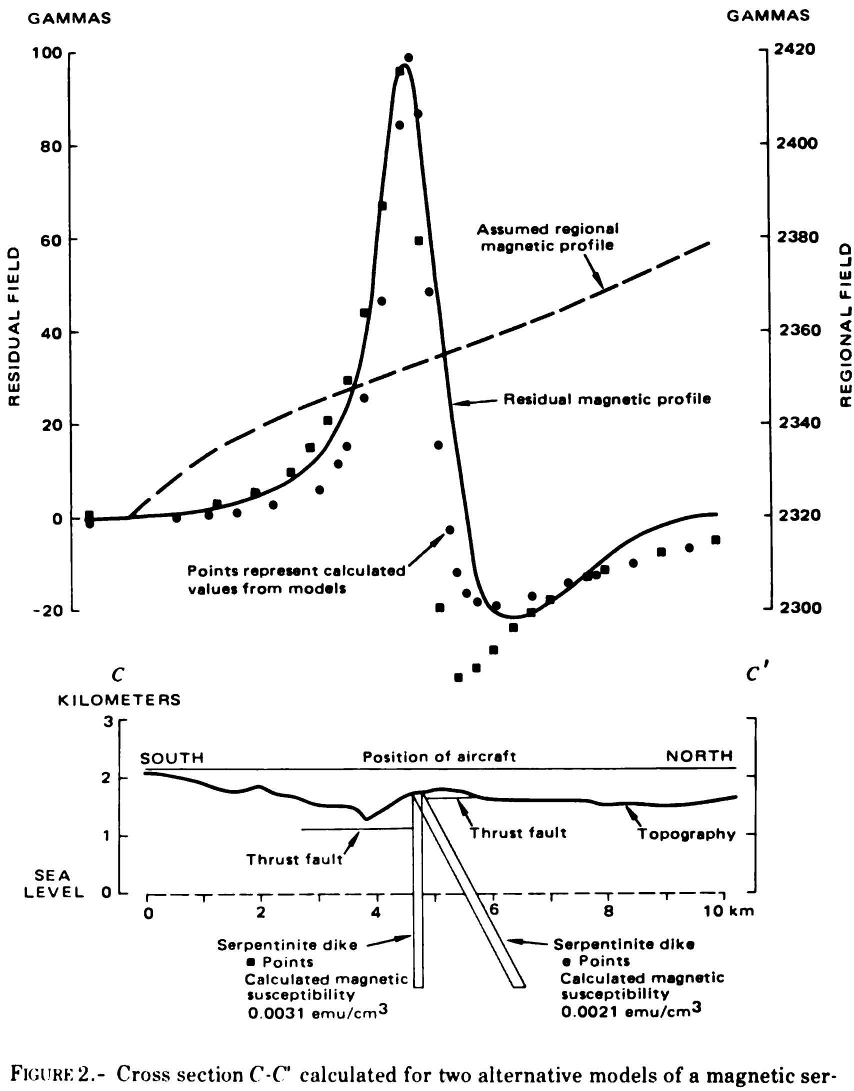



FIGURE 2.- Cross section C-C' calculated for two alternative models of a magnetic serpentinite dike. See text for discussion. Regional field values correspond to those on plate 2.

ganese, mercury, and massive sulfides containing copper (Davis, 1966). Orientation studies around several of these deposits just east of the study area provided comparative data useful for the geochemical evaluation. Most of the samples were analyzed in the field in mobile laboratories by a semiquantitative emission spectrographic technique. The geologic and analytical data were treated statistically to determine the normal or background concentrations of different elements and to determine threshold concentrations above which geochemical anomalies can be recognized. Geochemical maps (figs. 3-6) were plotted for selected elements and evaluated relative to the geology. The results of the geochemical investigation suggest a low potential for any metallic mineral deposit of economic significance in the study area. The complete data set on samples collected and analyzed during this study is available on tape from the U. S. Department of Commerce, National Technical Information Service (McDanal and others, 1977).

## SAMPLING AND ANALYTICAL METHODS

Rock samples of all the major rock types in the study area were collected during geologic mapping (pl. 1). Most of these rocks were relatively fresh and unaltered and provided data on the normal concentration ranges of elements important in the mineral evaluation. Float rocks and stream pebbles were examined in most of the drainages, and those with visible signs of mineralization or alteration were collected.

The rock samples were reduced to minus 6 mm in a jaw crusher, split with a Jones splitter, and ground to minus 0.1 mm in a vertical pulverizer equipped with ceramic plates. All samples were analyzed for 20 elements by a semiquantitative emission spectrographic method (Grimes and Marranzino, 1968) and for mercury by a vapor detector technique (Vaughn and McCarthy, 1964). The precision of the spectrographic method is given by Motooka and Grimes (1976). Selected samples were analyzed for gold by an atomic absorption method (Ward and others, 1969) and for uranium by a modification of a fluorimetric technique (Grimaldi and others, 1954).

Sediment samples were collected from selected drainages in and around the study area (pl. 1). Where possible, the sediment was taken at midchannel or in the most active part of the stream. The samples were stored in metal-free paper envelopes, air dried, and sieved to minus 0.18 mm. They were analyzed for 20 elements by the emission spectrographic method and for zinc by an atomic-absorption technique (Ward and others, 1969). The sediments were leached with oxalic acid to separate the iron and manganese oxide fraction for spectrographic analysis. The ability of these oxides to scavenge metals from solution and their significance in geochemical investigations is described by Chao and Theobald (1976). Pan concentrates were collected in many of the drainages (pl. 1), air dried, sieved to minus 0.4 mm, separated into magnetic and nonmagnetic fractions with a hand magnet, and hand ground in an agate mortar to minus 0.1 mm. Both fractions were analyzed for 20 elements by the emission spectrographic method and for mercury by the vapor-detector technique.

Water samples were collected from nine springs in the area and analyzed for copper, lead, zinc, and molybdenum by an atomic-absorption method and for sulfate by a turbidimetric technique (Tabatabai, 1974).

## METHODS OF EVALUATION

The geochemical evaluation was based on the distribution, variation, and geological association of selected elements in rock, stream sediment, pan concentrate, and water samples. The threshold value for an element separates normal or background concentrations from those that are significantly above backgrounds. Threshold values vary with different sampling methods; those given here (table 2) were determined using percent cumulative frequency plots as described by Boyle (1971). Where data were insufficient for statistical treatment, the threshold value was chosen by inspection. Concentrations above threshold are considered anomalous; only those samples containing an element in amounts exceeding its threshold were shown on geochemical maps. Distribution of copper, lead, and chromium in stream sediment is mapped as figures 3, 4, and 6, respectively, distribution of mercury in rock as figure 5. Partial analytical results for all samples containing anomalous amounts of one or more selected elements are given in table 3.

TABLE 2. - *Threshold values, in parts per million, for selected elements for different kinds of samples*

[Analytical methods: Mn, Cr, Cu, and Pb by emission spectroscopy for Hg by a vapor-detector method; N.d. not determined]

| Sample type | Mn | Cr | Cu | Pb | Hg |
|---|---|---|---|---|---|
| Rocks | 2,000 | 150 | 80 | 20 | 0.08 |
| Stream sediments | 1,800 | 550 | 90 | 20 | N.d. |
| Oxalic acid leach | 2,000 | 1,000 | 200 | 40 | N.d. |
| Nonmagnetic concentrate | 2,000 | 1,000 | 70 | 20 | .08 |

## GEOCHEMICAL INTERPRETATION

### COPPER

Minor amounts of copper are associated with manganiferous chert in several prospects a few kilometers east of the study area. Stream-sediment samples were collected near these prospects during a preliminary orientation study to provide data for geochemical compari-

TABLE 3. - *Partial analytical results of samples containing anomalous amounts of one or more selected elements*

[Analytical methods: S-Mn, S-Cr, S-Cu, S-Pb, S-Ag, S-Mo, and S-Zn by emission spectroscopy; INST. Hg by mercury vapor detector; and AA-Cu, AA-Pb, and AA-Zn by atomic absorption. N, indicates not detected at value shown; <, indicates less than value shown; >, indicates greater than value shown. Analysts: D. J. Grimes, R. W. Leinz, and W. H. Ficklin ]

**Rocks**

| Sample No. | Easting | Northing | S-Mn | S-Cr | S-Cu | S-Pb | INST. Hg | Other | Description |
|---|---|---|---|---|---|---|---|---|---|
| | | | | (Parts per million) | | | | | |
| BS23 | 53375 | 436725 | >5,000 | 70 | 150 | N20 | 5 | ··· | Mn prospect. |
| BS214 | 52960 | 436130 | 1,500 | 300 | 70 | N20 | N.02 | ··· | Volcanic. |
| BS217 | 53072 | 436028 | 3,000 | 50 | 300 | 50 | N.02 | ··· | Schists. |
| BS218 | 53070 | 436084 | 1,500 | 150 | 100 | N20 | N.02 | ··· | Volcanic. |
| BS219 | 52634 | 435638 | 1,000 | 300 | 20 | 20 | .02 | ··· | Sediment. |
| BS229 | 52638 | 435968 | 1,500 | 70 | 100 | N20 | <.02 | ··· | Volcanic. |
| BS232 | 52484 | 435755 | 1,500 | 200 | 150 | N20 | .04 | ··· | Do. |
| BS233 | 52588 | 435774 | 1,500 | 200 | 200 | N20 | N.02 | ··· | Do. |
| BS250 | 52668 | 435886 | 2,000 | 150 | 150 | N20 | N.02 | ··· | Metasediment. |
| BS254 | 52956 | 436145 | 1,500 | 500 | 100 | N20 | N.02 | ··· | Sediment. |
| BS255 | 52924 | 436205 | 1,500 | 500 | 200 | N20 | <.02 | 300 Zn | Do. |
| BS256 | 52842 | 436308 | 1,500 | 500 | 150 | N20 | .04 | ··· | Volcanic. |
| BS271 | 52744 | 436715 | 1,500 | 500 | 150 | N20 | .02 | ··· | Do. |
| BS2119 | 52498 | 436297 | 1,500 | 500 | 100 | 30 | <.02 | ··· | Sediment. |
| BS2120 | 52522 | 436275 | 5,000 | N50 | 50 | N20 | N.02 | ··· | Chert (Mn). |
| BS2131 | 52336 | 435767 | 1,000 | 150 | 100 | N20 | N.02 | ··· | Volcanic. |
| BS2140 | 52196 | 436150 | 1,500 | 100 | 100 | N20 | N.02 | ··· | Diabase. |
| BS2154 | 52256 | 435648 | 1,500 | 500 | 70 | N20 | <.02 | ··· | Volcanic. |
| BS2166 | 52211 | 436296 | 2,000 | 100 | 100 | N20 | N.02 | ··· | Diabase. |
| SM1R | 53296 | 435831 | >5,000 | 70 | 50 | N20 | .02 | 10 Mo<br>300 Zn | Mn prospect. |
| SM2R | 53400 | 435920 | >5,000 | 70 | 20 | N20 | .40 | 30 Mo<br>300 Zn | Do. |
| SM5R | 51641 | 436127 | 1,500 | 200 | 50 | N20 | .04 | ··· | Volcanic. |
| SM8R | 51936 | 435624 | 500 | 50 | 300 | N20 | N.02 | ··· | Chert float. |
| SM9R | 51807 | 435718 | 2,000 | N50 | 7 | N20 | .06 | 7 Mo | Diabase. |
| SM12R | 52476 | 436798 | 5,000 | N50 | 100 | 70 | .20 | 700 Zn | Fe-stained float. |
| BCP711 | 51800 | 436311 | 1,500 | 50 | 20 | N20 | .04 | 15 Mo | Volcanic. |
| BCP717A | 51751 | 436374 | 2,000 | 100 | 150 | N20 | .06 | ··· | Do.. |
| BCP728 | 51363 | 436535 | 1,500 | 300 | 70 | N20 | N.02 | ··· | Do.. |
| SM15R | 52334 | 435471 | >5,000 | 200 | 200 | 30 | .22 | 20 Mo<br>500 Zn | Float with sulfides. |
| SM16R | 52685 | 436863 | >5,000 | N50 | 5,000 | 30 | .10 | ··· | Do. |
| BCP732 | 52011 | 435988 | 1,000 | 200 | 70 | N20 | .06 | ··· | Diabase. |
| BCP742 | 51725 | 435909 | 1,000 | 200 | 50 | N20 | .06 | ··· | Volcanic. |
| SM21R | 52629 | 435491 | 500 | 100 | 10 | 20 | .30 | .5 Ag | Fe-stained float. |
| SM24R | 51349 | 436147 | 700 | N50 | 15 | N20 | .50 | ··· | Chert. |
| SM30R | 51484 | 435851 | 1,500 | 200 | 30 | N20 | .04 | ··· | Volcanic. |
| SM31R | 51596 | 435844 | 700 | 300 | 30 | N20 | .08 | ··· | Sediment. |
| SM32R | 51752 | 436443 | 1,500 | 2,000 | 20 | N20 | .08 | ··· | Serpentine. |
| SM33R | 51754 | 436450 | 700 | 1,500 | 7 | N20 | .30 | ··· | Do.. |
| SM35R | 53111 | 436572 | 700 | 200 | 5 | N20 | <.02 | ··· | Gneiss. |
| BCP749 | 51980 | 435952 | 1,500 | 150 | 100 | N20 | <.02 | ··· | Diabase. |
| SM36AR | 52680 | 436868 | >5,000 | 100 | 5,000 | 50 | .16 | 200 Zn | Float with sulfides. |
| SM36BR | 52680 | 436868 | 1,000 | 70 | 100 | 30 | .20 | ··· | Do. |
| SM36CR | 52680 | 436868 | 5,000 | 50 | 100 | N20 | .08 | ··· | Do. |
| SM36DR | 52680 | 436868 | 700 | N50 | 1,500 | 50 | .38 | 3.0 Ag<br>50 Mo<br>700 Zn | Do. |
| SM36ER | 52680 | 436868 | 3,000 | 3,000 | 10 | N20 | .06 | ··· | Float with minor sulfides. |

TABLE 3. - *Partial analytical results of samples containing anomalous amounts of one or more selected elements*—Continued

**Stream sediments**

| Sample | Easting | Northing | S-Mn | S-Cr | S-Cu | S-Pb | Other |
|---|---|---|---|---|---|---|---|
| SM1SS | 53292 | 435848 | 1,500 | 70 | 100 | N20 | ... |
| SM2SS | 53290 | 435825 | 3,000 | 150 | 150 | N20 | ... |
| SM3SS | 53300 | 435975 | 2,000 | 500 | 100 | N20 | ... |
| SM4SS | 53391 | 435824 | 2,000 | 300 | 100 | N20 | ... |
| SM6SS | 53331 | 436154 | 2,000 | >5,000 | 70 | N20 | 300 Zn |
| SM11SS | 51959 | 435621 | 1,500 | 700 | 70 | <20 | ... |
| SM12SS | 51970 | 435613 | 1,500 | 700 | 70 | 20 | ... |
| SM13SS | 51825 | 435727 | 2,000 | 100 | 50 | N20 | ... |
| SM14SS | 51704 | 435796 | 1,500 | 2,000 | 70 | N20 | ... |
| SM21SS | 52952 | 436736 | 1,000 | 700 | 70 | <20 | ... |
| SM22SS | 52874 | 436789 | 1,000 | 700 | 70 | <20 | ... |
| SM23SS | 52818 | 436815 | 1,000 | 700 | 50 | <20 | ... |
| SM24SS | 52440 | 436782 | 1,000 | 700 | 50 | <20 | ... |
| SM25SS | 52426 | 436760 | 1,000 | 1,000 | 30 | N20 | ... |
| SM28SS | 52256 | 435486 | 700 | 300 | 50 | 20 | ... |
| SM29SS | 52273 | 435500 | 1,000 | 200 | 50 | 30 | ... |
| SM30SS | 52332 | 435463 | 1,000 | 500 | 70 | 30 | ... |
| SM31SS | 52438 | 435421 | 1,000 | 200 | 70 | 20 | ... |
| SM33SS | 52641 | 435560 | 1,500 | 150 | 50 | 20 | ... |
| SM34SS | 52651 | 435577 | 1,500 | 150 | 50 | 20 | ... |
| SM35SS | 52800 | 435586 | 1,500 | 1,000 | 50 | <20 | ... |
| SM37SS | 52607 | 436821 | 1,000 | 1,000 | 30 | <20 | ... |
| SM38SS | 52714 | 436869 | 1,000 | 1,500 | 30 | N20 | ... |
| SM39SS | 51976 | 435863 | 2,000 | 150 | 30 | N20 | ... |
| SM40SS | 51856 | 435962 | 2,000 | 150 | 50 | <20 | ... |
| SM43SS | 52438 | 436486 | 700 | 700 | 50 | <20 | ... |
| SM44SS | 52476 | 436357 | 1,000 | 5,000 | 30 | <20 | ... |
| SM45SS | 52494 | 436338 | 1,000 | 1,000 | 50 | N20 | ... |
| SM46SS | 52529 | 435696 | 1,000 | 1,000 | 50 | 20 | ... |
| SM47SS | 52712 | 435657 | 1,000 | 1,000 | 50 | 20 | ... |
| SM53SS | 52221 | 436321 | 1,000 | 700 | 50 | N20 | ... |
| SM54SS | 52141 | 436264 | 1,500 | 150 | 50 | 20 | ... |
| SM55SS | 52050 | 435568 | 1,000 | 700 | 50 | 20 | ... |
| SM56SS | 52536 | 435498 | 1,000 | 300 | 50 | 50 | ... |
| SM63SS | 51373 | 436126 | 1,500 | 200 | 70 | 20 | ... |
| SM64SS | 51365 | 436144 | 1,500 | 300 | 100 | N20 | ... |
| SM67SS | 51232 | 435824 | 1,000 | 700 | 50 | <20 | ... |
| SM68SS | 51196 | 435852 | 700 | 3,000 | 20 | N20 | ... |
| SM69SS | 51177 | 436048 | 1,500 | 700 | 50 | N20 | ... |
| SM70SS | 51233 | 436127 | 1,000 | 1,500 | 50 | N20 | ... |
| SM81SS | 51847 | 436350 | 1,000 | 1,000 | 50 | N20 | ... |
| SM82SS | 52025 | 436494 | 1,500 | 700 | 70 | N20 | ... |
| SM83SS | 52821 | 436622 | 1,000 | 700 | 70 | 20 | ... |
| SM85SS | 52912 | 436566 | 1,000 | 300 | 70 | 20 | ... |
| SM87SS | 53144 | 436504 | 700 | 700 | 50 | <20 | ... |
| SM88SS | 52908 | 435746 | 1,000 | 150 | 70 | 20 | ... |
| SM89SS | 52660 | 436852 | 500 | 500 | 50 | 20 | ... |
| SM91SS | 52746 | 436878 | 700 | 300 | 50 | 20 | ... |
| SM92SS | 52448 | 436859 | 700 | 500 | 70 | 20 | ... |

**Stream sediments — oxalic acid leach fraction**

| Sample | Easting | Northing | S-Cr | S-Cu | S-Pb | Other |
|---|---|---|---|---|---|---|
| SM1X | 53292 | 435848 | 300 | 700 | N20 | ... |
| SM2X | 53290 | 435825 | 500 | 1,000 | N20 | ... |
| SM3X | 53300 | 435975 | 1,000 | 1,000 | N20 | ... |

TABLE 3. - *Partial analytical results of samples containing anomalous amounts of one or more selected elements—Continued*

**Stream sediments — oxalic acid leach fraction—Continued**

| Sample | Easting | Northing | S-Cr | S-Cu | S-Pb | Other |
|---|---|---|---|---|---|---|
| SM4X | 53391 | 435824 | 1,000 | 1,000 | N20 | ... |
| SM6X | 53331 | 436154 | 5,000 | 1,000 | 50 | ... |
| SM11X | 51959 | 435621 | 1,000 | 30 | N20 | ... |
| SM12X | 51970 | 435613 | 700 | 70 | 100 | ... |
| SM15X | 51679 | 435710 | 300 | 300 | N20 | ... |
| SM20X | 53118 | 436318 | 1,000 | 100 | N20 | ... |
| SM21X | 52952 | 436736 | 1,000 | 50 | 50 | ... |
| SM22X | 52874 | 436789 | 1,000 | 100 | 70 | ... |
| SM23X | 52818 | 436815 | 1,000 | 100 | 70 | ... |
| SM24X | 52440 | 436782 | 700 | 70 | 70 | ... |
| SM25X | 52426 | 436760 | 1,000 | 150 | 70 | ... |
| SM26X | 52434 | 436752 | 1,000 | 200 | 70 | ... |
| SM27X | 52492 | 436784 | 1,000 | 30 | 50 | ... |
| SM31X | 52438 | 435421 | 300 | 150 | 50 | ... |
| SM32X | 52461 | 435426 | 300 | 300 | 30 | 5 Mo<br>500 Zn |
| SM33X | 52641 | 435560 | 300 | 150 | 50 | ... |
| SM35X | 52800 | 435586 | 1,000 | 100 | <20 | ... |
| SM36X | 52581 | 436813 | 1,000 | 100 | <20 | ... |
| SM37X | 52607 | 436821 | 1,000 | 30 | N20 | ... |
| SM44X | 52476 | 436357 | 2,000 | 30 | N20 | ... |
| SM45X | 42494 | 436338 | 2,000 | 100 | N20 | ... |
| SM46X | 52529 | 435696 | 1,500 | 50 | 30 | ... |
| SM47X | 52712 | 435657 | 1,500 | 50 | 30 | ... |
| SM53X | 52221 | 436321 | 1,500 | 150 | N20 | ... |
| SM55X | 52050 | 435568 | 500 | 50 | 100 | ... |
| SM56X | 52536 | 435498 | 300 | 100 | 100 | ... |
| SM57X | 52397 | 436212 | 200 | 150 | <20 | ... |
| SM63X | 51373 | 436126 | 500 | 300 | 20 | ... |
| SM64X | 51365 | 436144 | 700 | 300 | N20 | ... |
| SM67X | 51232 | 435824 | 1,500 | 30 | N20 | ... |
| SM68X | 51196 | 435852 | 3,000 | 50 | 20 | ... |
| SM70X | 51233 | 436127 | 2,000 | 30 | N20 | ... |
| SM72X | 51347 | 436436 | 1,000 | 100 | N20 | 15 Mo |
| SM74X | 51503 | 436565 | 1,000 | 70 | 30 | ... |
| SM89X | 52660 | 436852 | 500 | 50 | 50 | ... |
| SM90X | 52734 | 436880 | 500 | 300 | 20 | 300 Zn |
| SM91X | 52746 | 436878 | 700 | 30 | 50 | ... |
| SM92X | 52448 | 436859 | 700 | 20 | 70 | ... |

**Pan concentrates — nonmagnetic fraction**

| Sample | Easting | Northing | S-Mn | S-Cr | S-Cu | INST. Hg | Other |
|---|---|---|---|---|---|---|---|
| SM3CNL | 53300 | 435975 | 1,500 | 700 | 100 | 0.02 | ... |
| SM4CNL | 53391 | 435824 | 1,500 | 1,000 | 100 | .04 | ... |
| SM6CNL | 53331 | 436154 | 3,000 | 1,000 | 100 | .06 | ... |
| SM11CN | 51959 | 435621 | 2,000 | 200 | 100 | .18 | ... |
| SM12CN | 51970 | 435613 | 1,500 | 200 | 50 | .12 | ... |
| SM14CN | 51704 | 435796 | 2,000 | 300 | 100 | .12 | ... |
| SM20CN | 53118 | 436318 | 1,500 | 3,000 | 50 | .16 | ... |
| SM21CN | 52952 | 436736 | 1,500 | 500 | 50 | .14 | ... |
| SM25CN | 52426 | 136760 | 1,000 | 2,000 | 30 | .16 | ... |
| SM26CN | 52434 | 436752 | 1,000 | 1,000 | 30 | .16 | ... |
| SM27CN | 52492 | 436784 | 1,000 | 3,000 | 30 | .08 | ... |
| SM28CN | 52256 | 435486 | 1,000 | 3,000 | 30 | .10 | ... |
| SM35CN | 52800 | 435586 | 1,500 | 3,000 | 50 | .08 | ... |
| SM36CN | 52581 | 436813 | 1,500 | 2,000 | 70 | .06 | ... |
| SM37CN | 52607 | 436821 | 1,500 | 3,000 | 30 | .04 | ... |

TABLE 3. - *Partial analytical results of samples containing anomalous amounts of one or more selected elements—Continued*

| Pan concentrates — nonmagnetic fraction—Continued | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sample | Easting | Northing | S-Mn | S-Cr | S-Cu | INST. Hg | Other |
| SM38CN | 52714 | 436869 | 1,500 | 3,000 | 30 | .04 | ... |
| SM42CN | 52435 | 436481 | 1,500 | 5,000 | 50 | .08 | ... |
| SM43CN | 52438 | 436486 | 1,500 | 2,000 | 50 | .06 | ... |
| SM44CN | 52476 | 436357 | 1,500 | 5,000 | 50 | .04 | ... |
| SM46CN | 52529 | 435696 | 1,500 | 1,500 | 30 | .08 | ... |
| SM49CN | 52678 | 436131 | 1,500 | 2,000 | 50 | .04 | ... |
| SM55CN | 52050 | 435568 | 1,000 | 3,000 | 50 | .12 | ... |
| SM63CN | 51373 | 436126 | 1,500 | 300 | 50 | .10 | ... |
| SM64CN | 51365 | 436144 | 1,500 | 1,500 | 50 | .06 | ... |
| SM66CN | 51399 | 436040 | 1,500 | 3,000 | 50 | .06 | ... |
| SM67CN | 51232 | 435824 | 1,500 | 2,000 | 50 | .06 | ... |
| SM68CN | 51196 | 435852 | 1,000 | 5,000 | 10 | .04 | ... |
| SM70CN | 51233 | 436127 | 1,500 | 1,500 | 50 | .02 | ... |
| SM73CN | 51508 | 436553 | 1,500 | 1,500 | 50 | .02 | ... |
| SM74CN | 51503 | 436565 | 1,000 | 3,000 | 50 | .06 | ... |
| SM75CN | 51559 | 436327 | 1,500 | 300 | 50 | .06 | 15 Mo |
| SM81CN | 51847 | 436350 | 1,500 | 1,500 | 50 | .04 | ... |
| SM83CN | 52821 | 436622 | 1,000 | 2,000 | 50 | .04 | ... |
| SM86CN | 53116 | 436573 | 1,500 | 1,500 | 50 | .08 | ... |
| SM87CN | 53144 | 436504 | 1,000 | 3,000 | 50 | .06 | ... |
| SM92CN | 52448 | 436859 | 1,000 | 2,000 | 30 | .04 | ... |

| Water samples — springs | | | | | | |
|---|---|---|---|---|---|---|
| Sample | Easting | Northing | AA-Cu | AA-Pb | AA-Zn | Other |
| SM1SP | 51935 | 435978 | .0012 | 0.0007 | 0.0250 | ... |
| SM41SP | 52004 | 435936 | .0110 | .0210 | .0150 | .0006 Mo |

sons. In one such comparison, a significant contrast is apparent in the distribution of anomalous amounts of copper in the oxalic acid fraction of stream sediments (fig. 3). Samples (1SS, 2SS, 3SS, 4SS, 6SS) from near the prospects contain 700-1,000 ppm copper in the leach fraction and are clustered; all other samples with anomalous values (15SS, 32SS, 63SS, 64SS, 90SS- pl. 1) contain no more than 300 ppm copper and occur sporadically. Copper minerals were seen in only a few float rocks collected immediately outside the study-area boundary. A sample from Bear Creek (8R- pl. 1) contained minor amounts of malachite (300 ppm copper) in chert, and several rocks from the North Fork of Stony Creek (16R, 36AR, 36DR- pl. 1) contained chalcopyrite (1,500-5,000 ppm copper) associated with pyrite in fractured sedimentary rocks. The Stony Creek rocks are probably float material from a group of prospects located on the north side of the creek outside the study area. One water sample (4SP- pl. 1) collected from a spring about 2 km northwest of Snow Mountain East was anomalously high in copper (0.011 ppm). This anomaly, however, appears to be very localized, as other samples collected nearby contained only normal amounts of copper. Distribution maps are not shown for copper in the other sample media collected because anomalous values were few and their distribution erratic. From the geochemical data, there is no reason to suspect that the study area contains significant economic deposits of copper.

### LEAD

The anomalous lead values in the stream sediments along the South Fork of Stony Creek (fig. 4) are from detritus of the cataclastic sedimentary rocks that crop out in the southeastern part of the study area (pl. 1). These rocks contain 20-50 ppm background lead; the volcanic and ultramafic rocks in the area average below 20 ppm. This geochemical lead anomaly, then, reflects only a difference in local geology and is not of economic significance. The highest lead values in the stream sediment and rocks were 50 ppm (56SS- pl. 1) and 70 ppm (12R- pl. 1), respectively. No visible lead minerals were identified in any of the samples collected.

### MERCURY

Mercury was detected in anomalous amounts in nine rock samples scattered throughout the study area (fig. 5). The highest mercury content (5.0 ppm) was found in a sample of manganiferous chert (BS23) collected from a prospect outside the study area on Elephant Hill about 8 km northeast of St. John Mountain. All other anomalous rock samples contained 0.5 ppm or less and showed no geochemical pattern indicative of an economic deposit. No mercury minerals were seen in any of the pan concentrates nor were any significant amounts of mercury detected in any other sample types.

### CHROMIUM

Stream-sediment samples that contain anomalous amounts of chromium (fig. 6) show where serpentinite bodies (pl. 1) are being eroded, for the background chromium content of serpentinite (1,000-3,000 ppm) is much greater than that of other rocks in the area (100-300 ppm). The anomalous chromium values are therefore not considered to be of economic importance, and no visible chromite was observed in any of the rocks collected.

### MANGANESE

No geochemical map for manganese is given in this report, as only a few samples contained anomalous concentrations of manganese. Several prospects east of the study area containing manganese associated with chert in volcanic rocks were examined during the orientation study. The geochemical data suggest there is little probability that such deposits exist within the study area.

### OTHER METALS

No geochemically significant amounts of gold, silver, zinc, cobalt, nickel, niobium, barium, boron, uranium, nor the rare earth elements were found during this study.

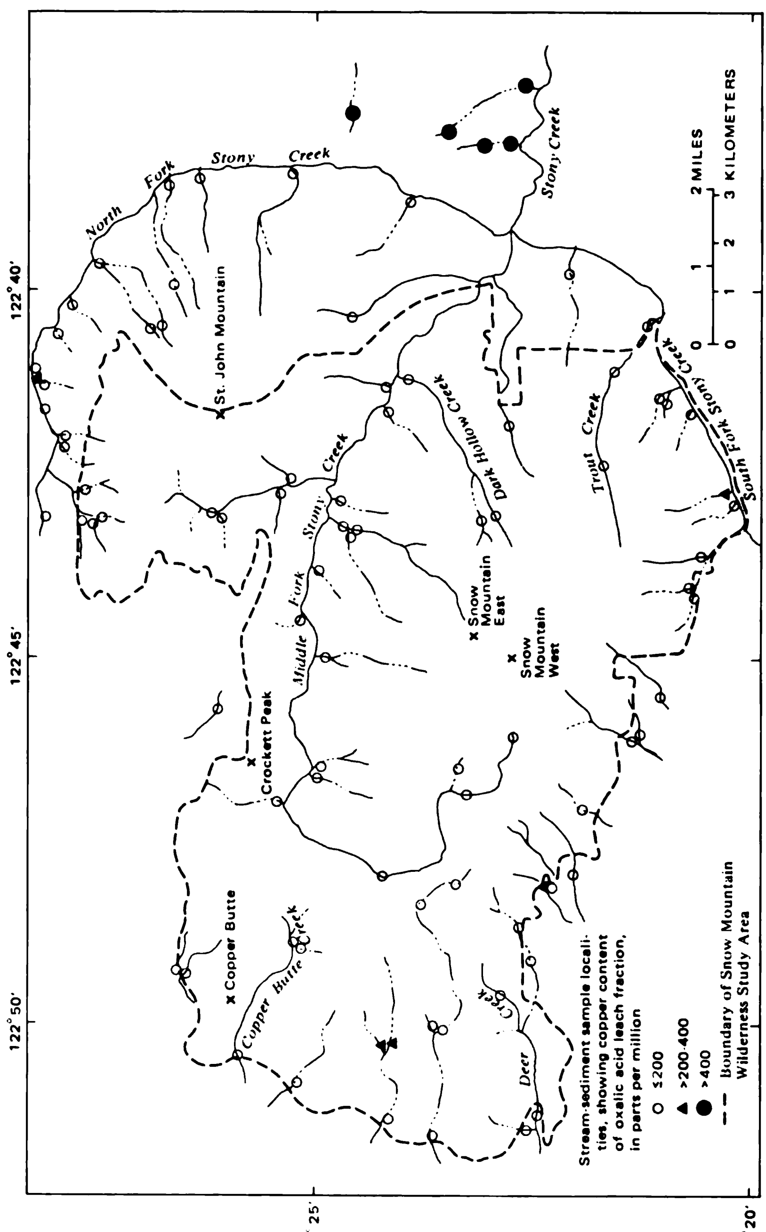



FIGURE 3.- Distribution of copper in the oxalic acid leach fraction of stream sediments.

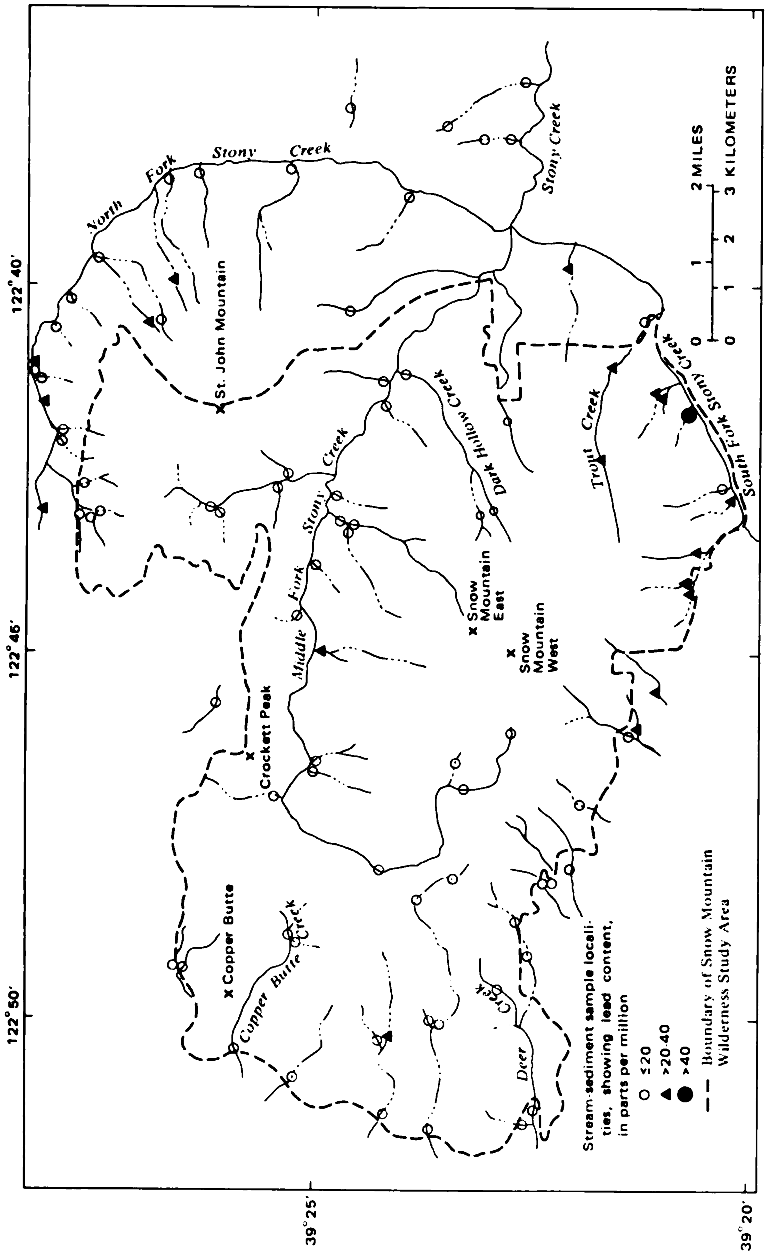



FIGURE 4.- Distribution of lead in stream sediments.

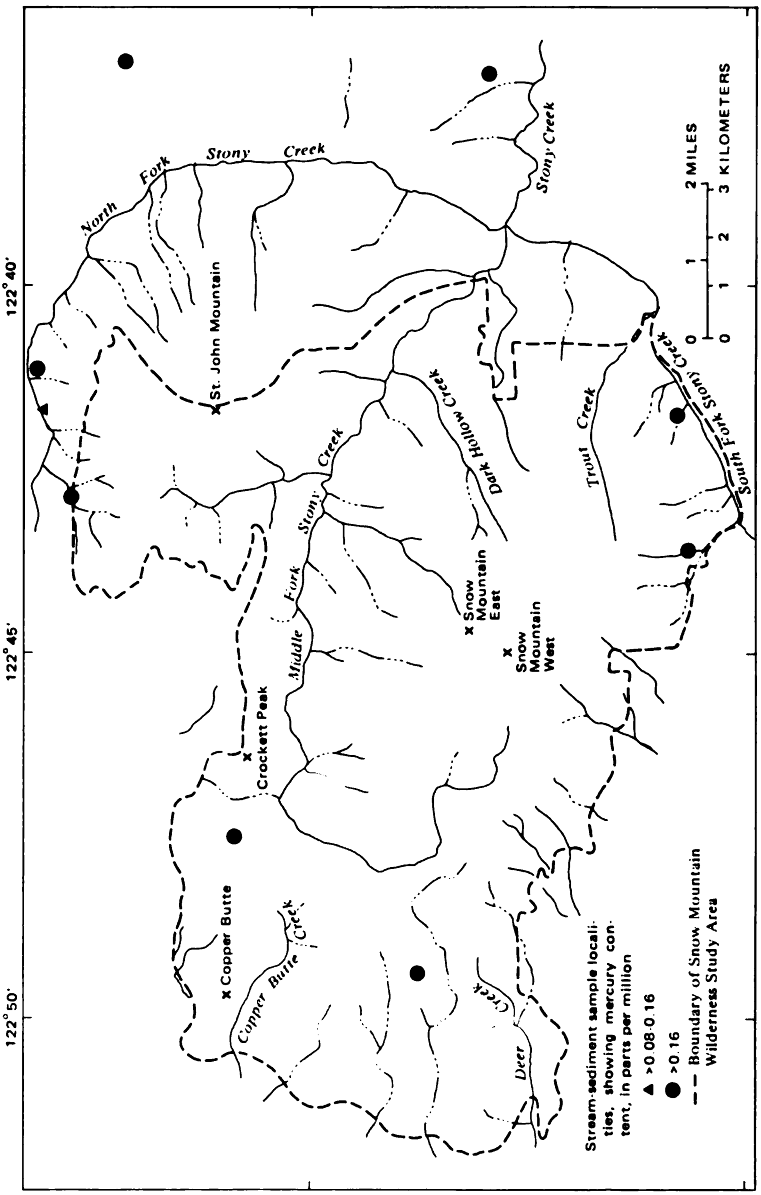



FIGURE 5.- Distribution of rocks containing anomalous amounts of mercury.

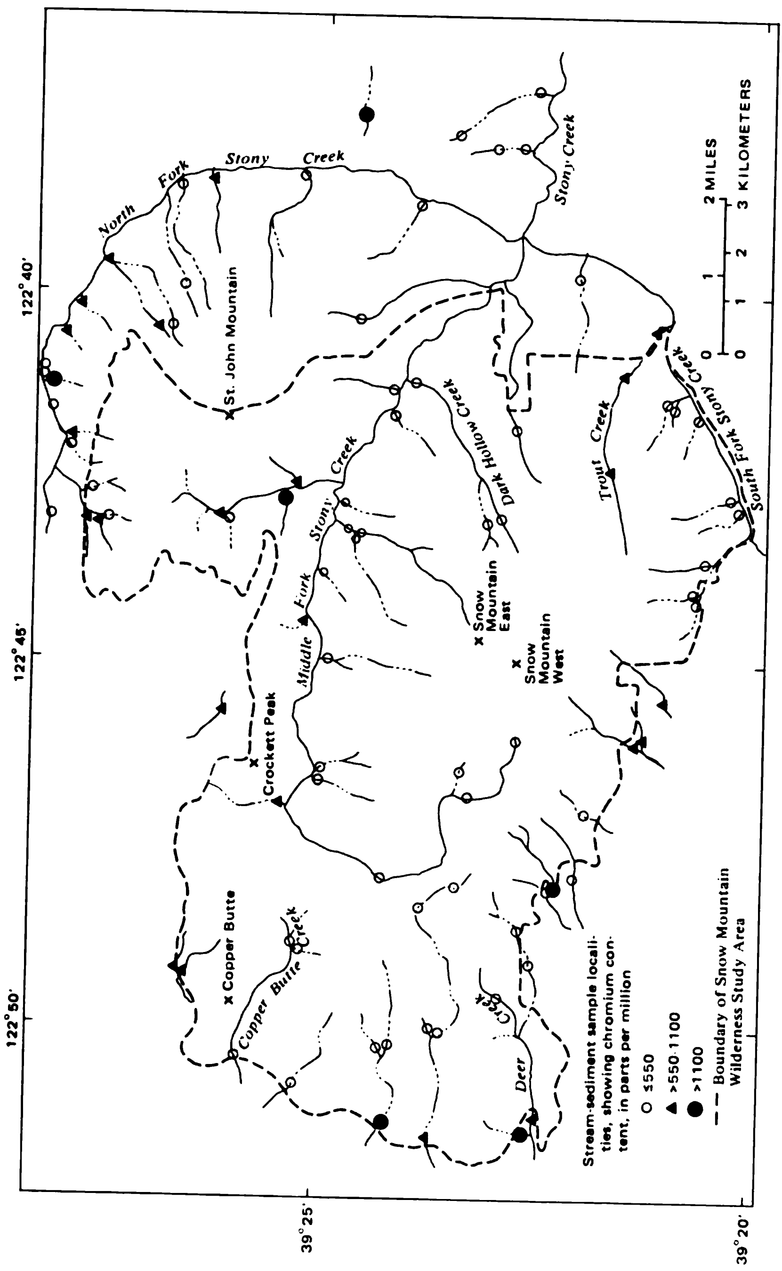



FIGURE 6.- Distribution of chromium in stream sediments.

### CONCLUSIONS

The results of the geochemical investigation suggest that the Snow Mountain Wilderness Study Area has a low potential for economic deposits of lead, chromium, manganese, mercury, gold, silver, and other related matals. The potential for massive sulfide deposits containing copper is also low as judged by the geochemical evidence, but this evaluation must be qualified somewhat because the entire klippe of volcanic rocks is considered geologically favorable terrane for deposits of the massive sulfide type.

## ECONOMIC APPRAISAL

The Snow Mountain Wilderness Study Area has been superficially prospected since the late 1800's. At least 19 claims have been staked, but no minable deposit has been found.

Most of the 19 unpatented lode claims in or near the study area were located for manganese. Samples of chert with manganese oxide coatings and veinlets from outcrops and prospect workings in or adjacent to the study area contained as much as 9.1 percent manganese. Small production has come from manganese oxide deposits 4.0 to 6.0 km east of the study area (fig. 7, and table 4, Nos. 6-11, 12-15). Samples from these deposits contained as much as 33.6 percent manganese. Nine samples of serpentinized peridotite with finely disseminated chromite from localities 2-5, 16, 17, 19, 27, and 32 (fig. 7) contained as much as 0.51 percent $Cr_2O_3$ and 0.26 percent nickel. Claims at these localities probably were located for chromite.

Nephrite and onyx are reported to occur in or near the study area, and at least one claim has been staked for each of these gemstones. Nephrite, one of the varieties of jade, is a tough, compact mineral in the isomorphous tremolite-ferroactinolite series, and is formed by metamorphism of ultramafic rocks. The P & C claims (fig. 7, Nos. 16, 17) were located for nephrite and are underlain by serpentinized peridotite with accessory chromite; only actinolite was found in rocks on the surface. One claim near the headwaters of Bear Wallow Creek in sec. 12, T. 18 N., R. 8 W., was located for onyx, a variety of chalcedony, or chert, with parallel bands of alternating colors. Chert does occur in the local sedimentary rocks, but no onyx was found during this investigation.

Surficial deposits of sand and gravel are along most drainages, especially along the Middle Fork of Stony Creek. Many of these deposits could be used for fill or aggragate locally. Rocks in the study area are not exceptionally good for use as building or dimension stone. Similar or better quality stone or rock could likely be found closer to markets.

All mines and prospects and many outcrops on claimed lands in and near the study area were sampled. Thirty-two rock samples in all were taken at sample localities shown on figure 7; table 4 gives sample descriptions and values. Sample localities in, or within 0.4 km of, the study are described in more detail at the end of this section.

The Snow Mountain Wilderness Study Area has a low mineral potential. Irwin (1960), in summarizing the mineral deposits in the northern Coast Ranges and Klamath Mountains, shows little past mineral production in the vicinity. Small amounts of manganese and chromite ores were mined near the area.

During World Wars I and II, manganese ore was mined about 5 km east of the study area. The Black Diamond mine (fig. 7, Nos. 12-15) produced 180 metric tons of ore according to U. S. Bureau of Mines records. Trask (1950, p. 62) reported that 4.5 metric tons of ore was shipped from the K. B. mine (fig. 7, Nos. 6-11), and about 45 metric tons of ore was stockpiled on the property at the time of his investigation. This ore is no longer on the property and presumably has been sold.

The Black Diamond mine is in thin-bedded northeast-striking steeply dipping red chert beds. Manganese oxides coat bedding and fracture planes. Scattered pods of psilomelane as much as 0.3 m in diameter and stringers to 1.3 cm wide occur in the beds. Four bulldozer cuts about 20 m long have been dug on the deposit. Three chip samples contained a maximum of 3.1 percent manganese and 10.3 percent iron. A select stockpile sample contained 19.3 percent manganese and 5.8 percent iron.

The K. B. mine, about 10 km north of the Black Diamond mine, is in folded and faulted thin-bedded highly iron oxide-stained chert beds with shale partings. A bed as much as 1.2 m thick on the K. B. No. 1 claim contains pyrolusite. Two manganese-bearing beds, 4.0 and 5.5 m thick, are exposed on the K. B. No. 4 claim. Chert containing pods and coatings of manganese oxides crops out on K. B. No. 4. The workings consist of seven bulldozer cuts trending east-west and one prospect pit. A caved adit was reported by Trask (1950, p. 62). Three chip samples taken across manganese-bearing beds contained as much as 5.7 percent manganese and 3.7 percent iron. Three grab samples of stockpiled material contained as much as 33.6 percent manganese and 7.6 percent iron.

The Old Glory (fig. 7, nos. 20-22) manganese property, south of Fouts Springs, is explored by a bulldozer cut and one circular prospect pit on a north-trending steeply-dipping manganese-bearing bed as much as 1.5 m thick. Two chip samples across the bed contained as much as 9.1 percent manganese and 29.5 percent iron.

Small-scale chromite mining from ultramafic rocks 8 km east of the area was done during World Wars I and II. Several northwest to east-west-trending peridotite (or serpentinite) bodies, emplaced

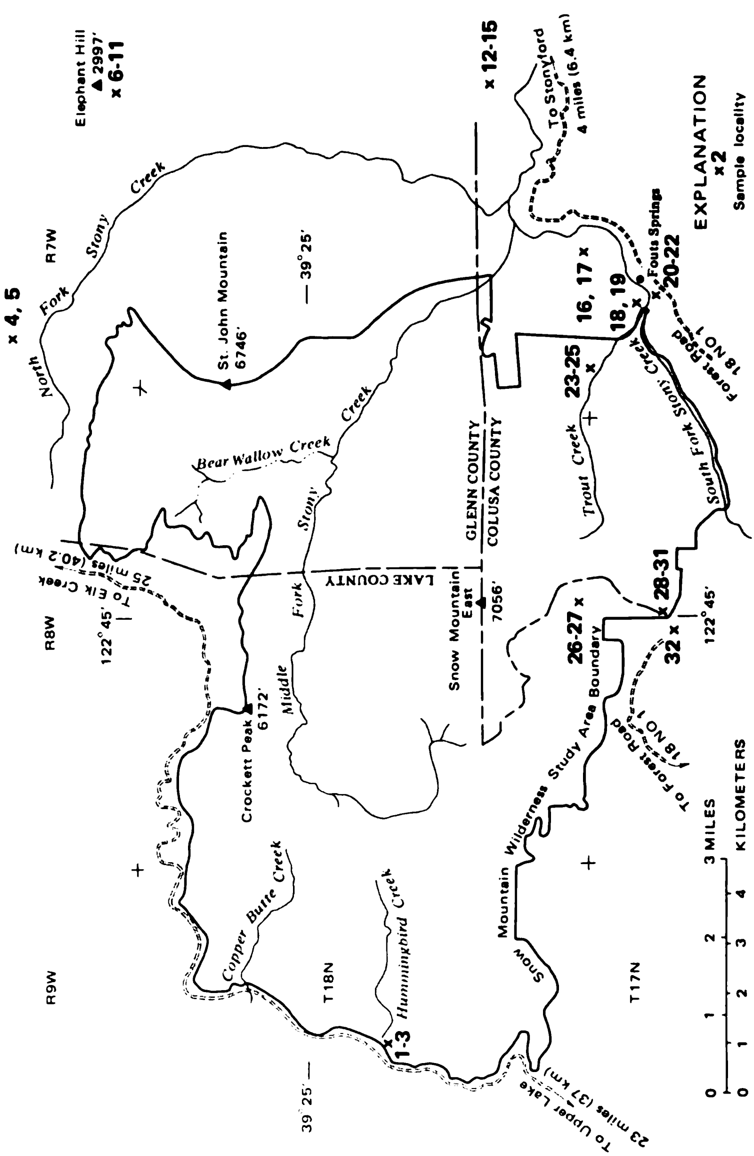



FIGURE 7.- Sample localities for U. S. Bureau of Mines samples.

along faults, extend into the study area. Finely disseminated chromite occurs sporadically in the peridotite. Nine samples of chromite-bearing peridotite, taken at the Long Shot claim (fig. 7, Nos. 2, 3), Queen Ann claims (fig. 7, Nos. 4, 5), P & C claims (fig 7, Nos. 16, 17), Moon Glade prospect (fig. 7, No. 19), Coyote claim (fig. 7, No. 29), and Summit Springs outcrop (fig. 7, No. 32), contained from 0.19 to 0.51 percent $Cr_2O_3$; most chrome-to-iron ratios were greater than 1 to 10.

### MINING CLAIMS

According to courthouse records for Colusa, Glenn, and Lake Counties, 19 lode claims were located in or adjacent to the study area between 1896 and 1976. No claims in the study area appear to be actively held.

### METHODS OF EVALUATION

Colusa, Glenn, and Lake County records, U. S. Forest Service files, and previous reports were examined to determine mining claim locations. Some claims were not found in the field because of vague location descriptions and (or) dense vegetation. All mines and prospects found in the study area were sampled and mapped. Some mines outside the study area, in particular the Black Diamond and K. B. manganese mines, were examined because similar host rocks occur in the area.

Data on production, history, and geology, of the Snow Mountain area were collected from published and unpublished reports and from claim owners. This information supplemented the field investigations.

Most of the 32 samples taken on or near claimed areas were chip samples from mineralized structures at workings or outcrops. Grab samples of dumps, or selected outcrops, were taken at caved or otherwise inaccessible workings. All samples were fire assayed for gold and silver and analyzed for other commodities where warranted. Each was checked for radioactivity and fluorescence. At least one sample from each prospect and select samples of serpentinized peridotite were analyzed for 42 elements by spectrographic methods to determine the presence of unsuspected minerals of possible value.

### MINES AND PROSPECTS

Prospects examined in, or within 0.4 km of, the Snow Mountain Wilderness Study Area are described in alphabetical order.

*Name*: Coyote prospect
*Index Map No.*: Fig. 7, Nos. 28-31
*Location*: SW¼ sec. 3 and NW¼ sec. 10, T. 17 N., R. 8 W., west of Fouts Springs

TABLE 4. - *Sample localities*

[Tr, trace; N, none detected; N.d., not determined]

| Name | Sample No. | Sample Type | Sample Length (ft) | Sample Description | Gold (oz per ton)[1] | Silver (oz per ton)[1] | Manganese (percent) | Iron (percent) | $Cr_2O_3$ (percent) |
|---|---|---|---|---|---|---|---|---|---|
| Long Shot claim | 1 | Chip | 20.0 | Iron oxide-stained metasedimentary and metavolcanic rocks. | Tr | N | 0.16 | 8.4 | N.d. |
| | 2 | do | 50.0 | Serpentinized peridotite | Tr | 0.1 | N.d. | 5.1 | 0.42 |
| | 3 | do | 100.0 | do | N | N | N.d. | 7.2 | .35 |
| Queen Ann claims | 4 | do | 15.0 | do | N | Tr | N.d. | 5.2 | .51 |
| | 5 | do | 15.0 | do | N | .1 | N.d. | 5.8 | .44 |
| K & B mine | 6 | do | 5.0 | Chert with manganese oxide coatings and veinlets. | Tr | N | 2.7 | 3.5 | N.d. |
| | 7 | Grab | -- | Stockpiled chert with manganese oxide veinlets and coatings. | N | N | 33.6 | 3.6 | N.d. |
| | 8 | do | -- | do | N | N | 26.3 | 7.6 | N.d. |
| | 9 | do | -- | do | N | N | 16.5 | 4.9 | N.d. |
| | 10 | Chip | 18.0 | Chert with manganese oxide coatings and veinlets. | Tr | N | 4.5 | 2.3 | N.d. |
| | 11 | do | 13.0 | do | Tr | N | 5.7 | 3.7 | N.d. |
| Black Diamond mine | 12 | do | 25.0 | do | N | N | .5 | 10.3 | N.d. |
| | 13 | Grab | -- | Stockpiled chert with manganese oxide veinlets and coatings. | N | .1 | 19.3 | 5.8 | N.d. |
| | 14 | Chip | 28.0 | Chert with manganese oxide coatings | Tr | N | 1.7 | 5.9 | N.d. |
| | 15 | do | 20.0 | do | Tr | N | 3.1 | 6.7 | N.d. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| P & C claims | 16[2] | do | 100.0 | Serpentinized peridotite | Tr | N | N.d. | 8.2 | .19 |
| | 17[3] | do | 100.0 | do | N | Tr | N.d. | 4.7 | .44 |
| Moon Glade prospect | 18 | Grab | .. | Siltstone and chert with quartz stringers. | Tr | N | N.d. | N.d. | N.d. |
| | 19[4] | Chip | 10.0 | Serpentinized peridotite | N | N | N.d. | 5.0 | .47 |
| Old Glory claim | 20 | do | 2.0 | Across chert with north-trending steeply dipping manganese oxide veinlets. | N | N | 9.1 | 29.5 | N.d. |
| | 21 | Grab | .. | Chert with manganese oxide coatings | N | N | 4.7 | 22.8 | N.d. |
| | 22 | Chip | 5.0 | Across chert with north-trending manganese oxide veinlets. | N | N | 5.3 | 25.6 | N.d. |
| Trout Creek prospect | 23 | do | .5 | Across shear zone in siltstone | N | N | N.d. | N.d. | N.d. |
| | 24 | do | 1.0 | do | N | N | N.d. | N.d. | N.d. |
| | 25 | do | 5.0 | Across iron oxide-stained chert | N | N | N.d. | N.d. | N.d. |
| Snow Mountain claim | 26 | do | 10.0 | Across chert with manganese oxide coatings. | Tr | N | .37 | 6.8 | N.d. |
| | 27 | do | 15.0 | do | Tr | N | .28 | 11.1 | N.d. |
| Coyote claim | 28 | do | 20.0 | Serpentinized peridotite | N | N | N.d. | 6.3 | .38 |
| | 29 | do | 2.0 | Across chert with manganese oxide coatings. | N | N | .11 | 17.7 | N.d. |
| | 30 | do | 2.0 | Across quartz vein | N | N | N.d. | N.d. | N.d. |
| | 31 | do | 3.0 | do | N | N | N.d. | N.d. | N.d. |
| Summit Springs outcrop. | 32 | do | 30.0 | Serpentinized peridotite | N | N | N.d. | 5.8 | .39 |

Metric conversions: feet × 0.3048 = meters; ounces (troy) per ton × 34.285 = grams per metric ton.
[2]Nickel content: 0.084 percent.
[3]Nickel content: 0.23 percent.
[4]Nickel content: 0.26 percent.

*Elevation*: 1,573 m (5,160 ft)

*Access*: Gravel and dirt roads southwesterly from Fouts Springs.

*History*: The claim was located by Emmett R. Wilkinson, June 30, 1940, for manganese.

*Geology of deposit*: Country rock is massive buff-colored chert and serpentinized peridotite. Fracture surfaces in the chert are coated by manganese oxides. The peridotite locally contains finely disseminated chromite. A 0.3- 0.9-m-thick quartz vein strikes N. 10° E. and dips 60° SE. in the chert; no sulfides were identified in the vein.

*Sampling*: Two chip samples of the quartz vein contained no concentrations of metallic minerals. One chip sample of the manganese oxide-coated chert had 0.11 percent manganese and 17.7 percent iron. A chip sample of the peridotite contained 0.38 percent $Cr_2O_3$, and 6.3 percent iron.

*Conclusion*: The property has low mineral potential.

*Name*: Long Shot claim

*Index Map No.*: Fig. 7, No. 1

*Location*: NE¼ sec. 22, T. 18 N., R. 9 W., along Hummingbird Creek.

*Elevation*: 792 m (2,600 ft)

*Access*: Paved and gravel roads westerly from Elk Creek, Calif.

*History*: The claim was located by Harold Wilkinson in 1950 as the Golden Bear; in 1957, he restaked it as the Long Shot.

*Geology of deposit*: Chert, siltstone, sandstone, and intercalated greenstone beds overlie serpentinized peridotite. About 10 percent of the overlying rocks are iron oxide stained. No concentrations of metallic minerals are exposed.

*Sampling*: Two chip samples of serpentinized peridotite outcrops contained 0.35 and 0.42 percent $Cr_2O_3$, and 7.2 and 5.1 percent iron. An outcrop sample of overlying sedimentary and metamorphic rocks contained 8.4 percent iron and 0.16 percent manganese. No sample had more than a trace of gold and (or) 3.42 g silver per metric ton (0.1 oz silver per ton).

*Conclusion*: The property has low mineral potential.

*Name*: Moon Glade prospect

*Index Map No.*: Fig. 7, Nos. 18, 19

*Location*: SW¼ sec. 5, T. 17 N., R. 7 W

*Elevation*: 634 m (2,080 ft)

*Access*: By road and trail west from Fouts Springs.

*Geology of deposit*: Country rock consists of serpentinized peridotite, siltstone, and chert with quartz stringers less than 1.3 cm thick. The stringers are slightly coated by iron oxides but contain no concentrations of metallic minerals.

*Development*: One sloughed prospect pit 4.6 m long and 1.5 m wide trends northerly. The pit's dump is large enough to indicate a short caved adit at the pit's north end.

*Sampling*: A grab sample of quartz stringers from the dump contained no gold or silver. One random chip sample of a serpentinized peridotite outcrop near the pit was 0.47 percent $Cr_2O_3$ and 0.26 percent nickel.

*Conclusion*: Sample analyses indicate that the property has a small potential for the discovery of nickel or chromium resources.

*Name*: Snow Mountain No. 1 and No. 2 claims

*Index Map No.*: Fig. 7, Nos. 26, 27

*Location*: SE1/4 sec. 34, T. 18 N., R. 8 W., about 1.6 km south of Snow Mountain East.

*Elevation*: 1,935 m (6,350 ft)

*Access*: By road and trail westerly from Fouts Springs.

*History*: The claims were staked by F. C. Wood in 1913.

*Geology of deposit*: Bedded red chert underlies the property. The beds strike N. 50° to 70° E., dip 30° to 45° SE., and are 5 to 15.2 cm thick. Manganese oxide coatings are as much as 0.6 cm thick on bedding and fracture surfaces.

*Sampling*: Two chip samples across the bedding planes contained 0.28 and 0.37 percent manganese and a trace of gold.

*Conclusion*: The property has low mineral potential.

*Name*: Trout Creek prospect

*Index Map No.*: Fig. 7, Nos. 23-25

*Location*: NE1/4 sec. 6, T. 17 N., R. 7 W., on north side of Trout Creek.

*Elevation*: 914 m (3,000 ft)

*Access*: By road and trail northwest from Fouts Springs.

*Geology of deposit*: Grayish-black siltstone and chert highly stained with iron oxide underlies the property. Northwest-trending steeply dipping shear zones 5 to 20 cm thick that contain brecciated country rock and vein quartz offset the strata.

*Development*: A 70-m-long adit is driven northeasterly in siltstone and chert.

*Sampling*: Two chip samples of shear zones and one chip sample of iron oxide-stained chert in the adit contained no concentrations of gold, silver, or other metallic minerals.

*Conclusion*: Sample analyses indicate low mineral potential.

## EVALUATION OF MINERAL RESOURCES

The geologic, geochemical, and geophysical data-gathering techniques and methods of interpretation described in this report are designed to test for those resources that geologists believe are most likely to be found in the geologic environment of the wilderness study area. They enable investigators to evaluate large areas rapidly and at relatively low cost. But to achieve these economies in time and cost, some sacrifices are made both in the level of detail and in the scope of the investigation. Unusual or unanticipated resources may or may not be detected, and even anticipated resources may escape detection if they are present in small amounts. Even taking into account these investigative limitations, the outlook for major mineral resources here is unpromising.

Neither the results of this investigation nor the records of previous work hint at any important undiscovered resources. Known resources such as mineral springs or volcanic rock suitable for crushing are not now being exploited, nor are they likely to be without unforeseen social or economic changes.

The potential for manganese, chrome, mercury, and copper was specifically examined because mineral deposits containing these elements have been mined in nearby areas in the past or because they have been mined in similar geologic settings elsewhere in the Coast Ranges. Mercury is an important commodity farther south in the Coast Ranges, but the nearest mines with a history of production are about 45 km southeast of Snow Mountain. No evidence of prospecting activity for mercury nor significant geochemical evidence for mercury deposits was found in the study area or in its surroundings.

Small amounts of manganese, chrome, and copper have been produced from rocks within a few kilometers of the study area, and the Gray Eagle chromite mine, with a sporadic history of production prior to 1945, was located about 40 km northeast of Snow Mountain (Rynearson and Wells, 1944; Dow and Thayer, 1946). Mining and exploration for these three elements peaked during World Wars I and II and at other times when normal sources of supply were interrupted. Despite geologically favorable terrane, especially for massive sulfide deposits, no evidence of important deposits of manganese, chrome, or copper was found in the study area.

Energy resources include oil and natural gas, coal, uranium, and geothermal energy. Some natural gas fields in the Sacramento Valley are only about 50 km east of Snow Mountain, but the gas fields are in different rocks and in a simpler structural setting than that near Snow Mountain. Most petroleum geologists view the abundant volcanic rock and the degree of structural deformation in this part of the Coast Ranges as unfavorable for the accumulation of petroleum fluids, and their exploration work has been concentrated in more favorable areas.

For somewhat different geologic reasons, the area is unlikely to contain important coal resources. Most coal is derived from woody vegetable matter that accumulates in a near-shore swampy or lagoonal environment at the margin of a relatively stable landmass. The rocks here record a different geologic environment, one dominated by volcanism, crustal instability, and deep-water depostition, an unlikely environment for deposits of coal.

Geothermal energy is exploited at the Geysers steam field, about 64 km south of Snow Mountain, and in 1977, other parts of the Coast Ranges were being explored for new sources of geothermal energy. Although the area around Snow Mountain has not been tested by drilling, the geothermal resource potential appears to be low. Only a few springs near Red Eye or Fouts Springs at the southeastern boundary of the study area are above normal groundwater temperature, and their thermal character is so slight as to be barely detectable.

Construction materials such as sand and gravel, limestone, and crushed rock are essential and widely distributed commodities whose values depend greatly on their proximity to a local market. Sand and gravel deposits in this area are smaller, of poorer quality, and less accessible than other deposits that are closer to present-day markets. Elsewhere in the Coast Ranges, limestone is found as lenses associated with volcanic rocks, and in some of these places it has been quarried for making cement. In this area, fist-size masses of limestone fill the spaces between pillows in a few flows of volcanic rock, but no larger bodies of limestone were observed. Crushed rock suitable for road surfacing and other uses could probably be obtained from some of the hardest little-altered volcanic rocks and diabase in the study area. Similar rocks near Stonyford have been used in this way, although most of the quarries were small and the crushed rock was used close to the quarry sites. The volume of rock judged suitable for crushing is large, but its value as a resource is diminshed because of its remoteness and poor accessibility and because similar volcanic rocks near Stonyford are closer to most of the potential markets for crushed rock.

Considerable resource potential was formerly attached to some of the mineral springs that issue from bedrock and from the bed of the South Fork of Stony Creek near Fouts Springs. The springs flow at rates of a few liters to 35 l per minute and several of them are thermal (24°C). Some are carbonated and palatable; others are sulfurous. Four of these springs, including Red Eye Spring, were once the chief attraction of the resort that operated at Fouts Springs from 1905 until about 1920. The water was used for both bathing and drinking, and some of it was bottled and marketed (Waring, 1915, p. 205-207, 267). Most of these springs are outside the boundary of the study area, but a few smaller mineral springs are inside. Partly because those inside the boundary are relatively small, but also because mineral spring resorts have declined in popularity, the resource potential of these springs is at best marginal.

At a few localities, the rocks in the study area exhibit mineralogic or color characteristics that are prized by amateur rock collectors. Deeply colored chert or jasper in the volcanic rocks and well-crystallized glaucophane schists are among the types most often collected. Specimen-quality material, however, is rare and is so widely scattered that in the context of this report it is not considered a resource.

From this summary of mineral resources, crushed rock appears to be the only significant potential resource. The volcanic rocks and diabase that could be used as a source of crushed rock are so located that their value would be greatest to a single user, the U. S. Forest Service. Although the Forest Service administers the area, few of these rocks have been crushed for surfacing the Forest Service roads that encircle it. This degree of nonuse can be interpreted as evidence that at this time even the crushed rock resource is not valued very highly.

## REFERENCES CITED

Aubury, L. E., 1908, The copper resources of California: California Mining Bureau Bulletin 50, 366 p.

Bailey, E. H., and Blake, M. C., Jr., 1974, Major chemical characteristics of Mesozoic Coast Range ophiolite in California: U. S. Geological Survey Journal of Research, v. 2, no. 6, p. 637-656.

Bailey, E. H., Blake, M. C., Jr., and Jones, D. L., 1970, On-land Mesozoic oceanic crust in California Coast Ranges, *in* Geological Survey Research 1970: U. S. Geological Survey Professional Paper 700-C, p. C70-C81.

Bailey E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks, and thier significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Berkland, J. O., 1973, Rice Valley outlier- new sequence of Cretaceous-Paleocene strata in northern Coast Ranges, California: Geological Society of America Bulletin v. 84, p. 2389-2406.

Berkstresser, C. F., 1968, Data for springs in the northern Coast Ranges and Klamath Mountains of California: U. S. Geological Survey Open-file Report, 49 p.

Boyle, R. W., 1971, Geochemical prospecting, *in* Encyclopedia of science and technology [3d ed.]: New York, McGraw Hill, p. 124-129.

Bradley, W. W., Hugeuenin, Emile, Logan, C. A., Tucker, W. B., and Waring, C. A., 1918, Manganese and chromium in California: California Mining Bureau Bulletin 76, 248 p.

Brown, R. D., Jr., 1964a, Thrust fault relations in the northern Coast Ranges, California, *in* Geological Survey Research 1964: U. S. Geological Survey Professional

Paper 475-D, p. D7-D13.

—— 1964b, Geologic map of the Stonyford quadrangle, Glenn, Colusa, and Lake Counties, California: U. S. Geological Survey Mineral Investigations Field Studies Map MF-279, scale 1:48,000.

Chao, T. T., and Theobald, P. K., 1976, The significance of secondary iron and manganese oxides in geochemical exploration: Economic Geology, v. 71, no. 8, p. 1560-1569.

Chapman, R. H., Bishop, C. C., Chase, G. W., and Gasch, J. W., 1974, Bouguer gravity map of California, Ukiah sheet: California Division of Mines and Geology, 1 sheet, scale 1:250,000, 6 p.

Davis, F. F., 1957, Mercury, *in* Mineral commodities of California: California Division of Mines Bulletin 176, p. 341-356.

—— 1966, Economic mineral deposits in the Coast Ranges, *in* Bailey, E. H., editor, Geology of northern California: California Division of Mines and Geology Bulletin 190, p. 315-322.

Dow, D. H., and Thayer, T. P., 1946, Chromite deposits of the northern Coast Ranges of California, *in* Geological investigations of chromite in California: California Division of Mines Bulletin 134, pt. 2, chap. 1, p. 1-38.

Eric, J. H., 1948, Tabulation of copper deposits of California, *in* Copper in California: California Division of Mines Bulletin 144, p. 199-357.

Fabiano, E. B., 1975, Magnetic declination in the United States- epoch 1975.0: U. S. Geological Survey Miscellaneous Investigations Series Map I-911, scale 1:5,000,000.

Fabiano, E. B., Peddie, N. W., and Jones, W. J., 1976, Magnetic total intensity in the United States- epoch 1975.0: U. S. Geological Survey Miscellaneous Investigations Series Map I-915, scale 1:5,000,000.

Goddard, E. N., chairman, and others, 1963, Rock-color chart: New York, Geological Society of America, 11 p.

Grimaldi, F. S., May, I., Fletcher, M. H., and Titcomb, J., 1954, Collected papers on methods of analysis for uranium and thorium: U. S. Geological Survey Bulletin 1006, 184 p.

Grimes, D. J., and Marranzino, A. P., 1968, Direct-current arc and alternating current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U. S. Geological Survey Circular 591, 6 p.

Griscom, Andrew, 1966, Magnetic data and regional structure in northern California, *in* Bailey, E. H., editor, Geology of northern California: California Division of Mines and Geology Bulletin 190, p. 407-417.

Holway, R. S., 1911, An extension of the known area of Pleistocene glaciation to the Coast Ranges of California: American Geographical Society Bulletin, v. 43, p. 161-170.

Irwin, W. P., 1960, Geologic reconnaissance of the northern Coast Ranges and Klamath Mountains, California, with a summary of mineral resources: California Division of Mines Bulletin 179, 80 p.

Jennings, C. W., and Strand, R. G., compilers, 1960, Geologic map of California, Olaf P. Jenkins edition, Ukiah sheet: California Division of Mines, scale 1:250,000.

Lanphere, M. A., 1971, Age of the Mesozoic oceanic crust in the California Coast Ranges: Geological Society of America Bulletin, v. 82, p. 3209-3212.

McDanal, S. K., Grimes, D. J., and Leinz, R. W., 1977, Magnetic tape containing spectrographic and chemical analysis of geologic materials from the Snow Mountain Wilderness study area, Colusa, Glenn, and Lake Counties, California: U. S. Geological Survey Report, U.S.G.S. ERT016 [Available from U. S. Dept. Commerce National Technical Information Service, Springfield, VA 22161. ]

McPherson, G. J., 1977, An on-land seamount- the Snow Mountain volcanic complex, northern California Coast Ranges [abs.]: American Geophysical Union Transactions, v. 58, no. 12, p. 1245.

Motooka, J. M., and Grimes, D. J., 1976, Analytical precision of one-sixth order of semiquantitative spectrographic analysis: U. S. Geological Survey Circular 738, 25 p.

Pessagno, E. A., Jr., 1977, Upper Jurassic radiolaria and radiolarian biostratigraphy of the California Coast Ranges: Micropaleontology, v. 23, no. 1, p. 56-113.

Rynearson, G. A., and Wells, F. G., 1944, Geology of the Grey Eagle and some nearby chromite deposits in Glenn County, California: U. S. Geological Survey Bulletin 945-A, p. 1-22.

Tabatabai, M. A., 1974, A rapid method for determination of sulfate in water samples: Environmental Letters, v. 7, no. 3, p. 237-243.

Trask, P. D., 1950, Geologic description of manganese deposits of California: California Division of Mines Bulletin 152, 378 p.

Trask, P. D., Wilson, I. F., and Simons, F. S., 1943, Manganese deposits of California, a summary report, *in* Manganese in California: California Division of Mines Bulletin 125, p. 51-215.

Turner, F. J., and Verhoogen, John, 1960, Igneous and metamorphic petrology [2d ed.]: New York, McGraw Hill, 694 p.

Vaughn, W. W., and McCarthy, J. H., Jr., 1964, An instrumental technique for the determination of submicrogram concentrations of mercury in soils, rocks, and gas, *in* Geological Survey Research 1964: U. S. Geological Survey Professional Paper 501-D, p. D123-D127.

Ward, F. N., Nakagawa, H. M., Harms, T. F., and VanSickle, G. H., 1969, Atomic-absorption methods of analysis useful in geochemical exploration: U. S. Geological Survey Bulletin 1289, 45 p.

Waring, G. A., 1915, Springs of California: U. S. Geological Survey Water-Supply Paper 338, 410 p.

——— 1965, Thermal springs of the United States and other countries of the world- a summary, revised by R. B. Blankenship and Ray Bentall: U. S. Geological Survey Professional Paper 492, 383 p.

GPO 789-036/8